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Some new and little-known meteorites found in Western Australia.

(With Plates VI–IX.)

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Dalgaranga.

Siderite (Om), many small fragments, fell before 1910, found 1923.

WHEN some publicity was given recently in the press to the Gundaring and Kumerina finds, which are described below, Mr. G. E. Willard called upon me in regard to a meteorite which had fallen on Dalgaranga sheep station (27° 45′ S., 117° 5′ E.). He stated that when he was a manager of this station in 1923 he found a crater measuring 65 yards across at the top, 50 yards at the bottom, and 15 feet deep. The surface of the country was 'hard conglomerate' (laterite?—E. S. S.), and pieces of rock up to one cubic yard were pushed up out of the hole, as if there had been an explosion. The NW. side had been thrust upwards more than any other, indicating that the meteorite came from the SE. In and around the crater Willard found 'a hatful' of small ragged pieces of iron like the Henbury (Central Australia) fragments. These original specimens unfortunately had since been mislaid, but he was able to secure for me from the present manager of the station a 40-gram piece. Ten miles to the SE. he had found in 1923 another small piece of iron, also now lost. In that year a mulga bush (*Acacia* sp.) 15 feet high was growing in the bed of the crater, indicating that the meteorite had fallen prior to about 1910. No scientist has ever visited the crater, but Willard's story confirmed what I had heard already in Yalgoo, the nearest town to Dalgaranga, when I was there in 1932.

The 40-gram piece from the crater is ragged and deeply indented, with a 4-mm. circular perforation on one edge, where a rod of troilite has

burnt out. The whole surface is covered with a fused oxide film. In one hollow this is 5 mm. thick, indicating possibly an original silicate inclusion. A piece of the metal which was sawn off was freed from oxide and then found to contain 8·63% of nickel. The small surface exposed by the saw cut was polished and etched. It gave a very confused figure with many curved boundaries, the result probably of the high temperature produced by friction in the air and impact on the ground, and strains resulting from the impact and explosion. What appear to be bent kamacite plates are very variable in thickness, from 0·1 to 0·7 mm. Tentatively I have classified the meteorite as a medium octahedrite. It is hoped some time to visit the crater and obtain more specimens for further investigation.

Dowerin.

Siderite, many small fragments, first known 1932.

In 1932 when visiting Dowerin I was shown several small ragged fragments of iron with a black oxidized surface, which were said to be typical of a large number found on the surface some distance south of the town after a scrub fire. One fragment in my collection weighs 0·35 gram. They are like the Henbury fragments and almost certainly of meteoritic origin. Dowerin is at 31° 12′ S., 117° 4′ E.

Gundaring.

Siderite (Og–Ogg), one mass of 248 lb. (112·5 kg.), seen to fall April 6, 1930, found May 20, 1937.

This meteorite, measuring $17 \times 16\frac{1}{2} \times 9$ inches ($43 \times 42 \times 23$ cm.), caused a considerable sensation when it was seen to fall at 2 p.m. in bright daylight by a large number of people at various points up to nearly 200 miles away from where it touched the ground at Gundaring, close to the spot predicted by the Government Astronomer (Mr. H. B. Curlewis) after collating all the reports. He estimated that it travelled in a SSE. direction, and first became visible above a point 10 miles SW. of the town of Pingelly and about 50 miles to the NNW. of Gundaring, which is at 33° 18′ S., 117° 40′ E. During the flight it appears certain that it burst into two halves, only one of which has been found. Its fall was accompanied by the usual phenomena of an intense drumming or rumbling noise, and severe vibration of the air, with a loud explosion almost over the village of Cuballing, after which several observers stated that two objects were visible travelling along almost parallel courses.

The public interest was keenly aroused and a number of long articles about it appeared in the daily press. From time to time a search for the object was made by local farmers and by residents of the nearby town of Wagin. In August, 1931, an australite of 10 grams was found near Gundaring, and was thought at first to be connected with the fall, being possibly part of a large shower resulting from the disintegration of a molten meteorite. This on consideration appeared extremely unlikely, and that there was no connexion is proved by the fact that no further australites have been reported from the district.

It was not till May, 1937, that F. Quinn found this large iron on his farming block no. 14355 close to the Cancanning public hall, nine miles NNE. of Gundaring. There is good reason to believe that it is one half of the object seen to fall in 1930. It was found right on the surface of the ground, which it had indented to only a slight extent, one reason for which was probably its low angle of impact, 45° or less. It was lent to the writer in 1937 to exhibit at a meeting of the Royal Society of Western Australia, after which it was held by a friend of the finder till February, 1938, when I again obtained a loan of it with permission to remove a portion for examination. Ultimately it will probably find a resting-place in the Western Australian Museum or Perth Observatory. Fig. 1 (pl. VI) shows its appearance.

The surface is broadly and not very deeply eroded. There were only comparatively few, 0·5–1·0 cm., roughly hemispherical pits caused by the rapid burning out of troilite nodules during the flight through the air. The troilite is in spheroids and amygdales rather than cylinders, only one cavity of the latter type being observed, 1·5 cm. deep by 0·5 cm. in diameter. The skin of slag is very thin, and dark brown to black in colour.

The slice removed weighed just under 4 lb., and the sawn section measuring 14×8 cm. was polished and etched, bringing out a very clear and beautiful crystallization, shown in fig. 2. Over almost the whole area the kamacite is crystallized in three parallel sets of plates, each highly schillerized, and making angles of approximately 60° with one another. The blades range from 0·5 to 2 mm. wide, with an average of about 1·4 mm., which would place the meteorite at the lower end of the broad octahedrite class, Og. Round a 1 cm. nodule of troilite, there is an irregularly oriented group of much wider plates, several reaching 4 mm., and having somewhat scalloped edges, similar to those in Youndegin, described by Brezina, and in Wonyulgunna, described below. As a whole, therefore, the meteorite overlaps into the broadest group, Ogg,

in this way also resembling the Youndegin fall. There are the usual thin plates of taenite bordering all the kamacite, and a number of interstitial areas of eutectic (plessite). Many of these show an octahedral arrangement of the very narrow secondary blades of kamacite. Two small inclusions of cohenite are seen in the section, each about 6×1–2 mm. These were noticeable in sawing the slice, being so hard as to blunt the saws in a very short time, and delay the cutting quite appreciably. The rest of the section was comparatively soft to cut. The nickel content of the mass is 8·18%. No complete analysis has been made of it.

Kumerina.

Siderite (Of), one mass of 118 lb. (53·5 kg.), found 1937.

In February, 1937, W. G. Armstrong sent a 35-gram fragment of iron to the *Western Mail* newspaper, which he had broken from a large mass he had found close to Batthewmurnana Hill, which is 20 miles SSE. of the centre of the Kumerina copper field. The position of the find was approximately 24° 55′ S., 119° 25′ E. Arrangements were made for the whole mass to be forwarded to the Western Australian Museum, where it now lies intact, except for a piece weighing 2·6 lb., used first for analysis and physical examination, and then presented to the British Museum (Reg. no. 1938,220).

The whole mass, whose appearance is shown in fig. 3, measured $14 \times 10 \times 10$ inches ($35 \times 25 \times 25$ cm.). One end is smoothly convex, the other end, and the central girdle, deeply and broadly eroded, showing comparatively few but large thumb-marks. Only two rather small cylindrical holes were noted from which rods of troilite had burnt out.

The iron was very hard to saw and file. No complete analysis has been made, but the nickel content of clean filings was determined to be 9·55%, which lies within Farrington's normal range for fine octahedrites, viz. 8–10·5% Ni+Co. The specific gravities of two fragments of 33 and 47 grams are 7·73 and 7·53. On a section $12{\cdot}5 \times 6$ cm. two small nodules of troilite were observed, 3–4 mm. in diameter. Several ragged pieces of cohenite can be seen under the microscope. The crystallization is unevenly developed, in some areas almost complete, in others represented only by occasional plates or small groups of plates in a structureless background. In such cases the kamacite plates are often lenticular. The kamacite lamellae are 0·2–0·4 mm. wide, but a few broader ones are seen surrounding cohenite (fig. 4).

Landor.

Siderite (Of), one mass of about 20 lb. (9 kg.), first known 1931.

In 1931 a Mr. Murphy brought to me five small well-crystallized octahedral fragments of heat-oxidized iron, broken from the ragged edge of a meteorite which he said weighed about 20 lb. It had recently been found near the head of the Wooramel river on Landor sheep station (25° S., 117° E.). The fragments in the writer's collection weigh 2·6 grams. It was not easy on such small surface material to determine the class to which the iron belongs. On polishing and etching one small piece, some kamacite plates 0·3–0·5 mm. in width were seen, as well as an area of eutectic. The class appears to be 'fine octahedrite'. It is hoped that in the future the whole meteorite may be obtained for the Western Australian Museum.

Mellenbye.

Stone (Cw), broken fragment of 12 oz. (337 gm.), found before 1932.

When I was in Yalgoo in 1932 I observed this fragment on a shelf in an hotel, and persuaded the lessee to give it to me. It appeared to form one-fourth or less of the whole original body, which was said to have been found by two gold prospectors between Mellenbye and Kadji-Kadji station homesteads at about 28° 51′ S., 116° 15′ E. The brown fused crust is intact on two sides, and the interior much rusted. The specific gravity is 3·32, indicating the presence of about 5% of nickel-iron. The mass was sawn in the British Museum, and a piece of 81 grams kept there (Reg. no. 1934,623), the remainder being returned to Perth, where it is still in my possession pending an opportunity to analyse it. Dr. L. J. Spencer, who examined it at the British Museum, says it belongs to the common type of chondrite, very like Silverton,[1] which has been described as a 'white hypersthene-olivine-chondrite'. It would come within Prior's group 3 or 4. A polished surface is heavily stained throughout by rust, and shows numerous minute specks and threads of metallic nickel-iron.

Milly-Milly.

Siderite (Om), one mass of 58¼ lb. (26·5 kg.), found 1921.

In the Annual Report of the Geological Survey for 1921[2] there was a brief statement of the collection of this meteorite by an aborigine on Milly-Milly sheep station at 26° S., 116° 30′ E. The meteorite had been

[1] L. J. Spencer, Min. Mag., 1934, vol. 23, p. 569.

[2] Ann. Rep. Geol. Surv. W. Austr., 1922, for 1921, p. 53.

known to the natives for many years. It was presented to the Western Australian Museum in the same year, and the main mass is still there. By courtesy of the curator I have been enabled to investigate it in some detail.

The mass measured $10 \times 9 \times 4$ inches ($25 \times 23 \times 10$ cm.), and the gross weight was $58\frac{1}{4}$ lb. (26·5 kg.). It is very deeply and broadly thumb-marked on both sides (fig. 5), but shows no signs of burnt-out troilite rods or nodules on the surface, or of unoxidized troilite on the one cut face. The iron was very hard to cut, and during the cutting small octahedral fragments, with thinly oxidized faces having a solid angle of $70\frac{1}{2}°$, broke off the edges of the cut. It is a medium octahedrite, with average width of kamacite plates 1·2 mm., the structure being very perfectly and strongly marked after etching. All the kamacite plates show an oriented schiller, but no flecking (fig. 6). The centres of the figures are occupied by eutectic with parallel structure. No cohenite was observed on the one section, and schreibersite is not prominent. Two small oval masses of troilite or daubreelite (?) were found to colour very readily, and stain the surrounding kamacite during etching. An analysis was made of a sawn-off fragment with the following results:

Fe.	Ni.	Co.	Cu.	Mg.	P.	S.	C.	Si.	Total.
(91·16)	7·84	0·77	nil	nil	0·20	0·01	0·02	nil	100·00

Premier Downs III.

Siderite (Om), one mass of $3\frac{1}{2}$ oz. (99 gm.), first known 1911.

In 1912 and 1914 Simpson and Bowley[1] described two small metallic meteorites (group Om) found on Premier Downs station which occupies part of the Nullarbor Plain. These weighed respectively 3·9 and 4·1 oz. (112 and 116 grams), and were said to have been found 8 miles apart.

In 1918 a third similar iron, weighing 99 grams and coming from the same area, was presented to the Western Australian Museum by Mr. Alister Ewing. It has the same knuckle-bone shape as the other two, and is covered with a thin fused crust of oxide, except on one exposed corner, where there is a crystalline fracture. That it had lain for some years on the ground is proved by the fact that a thin layer of travertine encrusts about one-third of its surface.

All three pieces probably belong to one shower. The approximate site of the fall is 31° 0′ S., 127° 20′ E.

[1] Ann. Rep. Geol. Surv. W. Austr., 1912, for 1911, p. 10. E. S. Simpson, Bull. Geol. Surv. W. Austr., 1912, no. 48, pp. 87–89; E. S. Simpson and H. Bowley, ibid., 1914, no. 59, pp. 205–209.

Thangoo?

It may hardly seem legitimate to include this in a description of meteorites, as, although it was seen to fall close to the observer, it has not yet been found. The unusual circumstances of its fall are, however, my justification.

Flying from Carnarvon to Broome at a height of 1500 feet and in the dark, at 7.10 p.m. on June 15, 1936, Pilot J. M. Woods was startled by a brilliant bluish light which suddenly lit up the wings of the plane like a search-light. He was then over Thangoo station at 18° 30′ S., 122° 0′ E. Banking the machine he saw the trail of a meteorite only 600 yards away. He stated that it looked very brilliant, a long red tail extending right across the sky from the bluish-white glaring head, which he saw strike the ground quite near the coast. The path was at an angle to the ground, and the glare lit up all the surrounding country for some moments. On arriving at Broome, 40 miles farther on, people waiting on the aerodrome said they had seen the fall from there. He suggested that some unexplained aeroplane accidents might be due to collision with meteorites.

Tieraco Creek.

Siderite (Of–Om), one mass of 92 lb. (41·7 kg.), found before 1922.

This meteorite has been fully described by T. Hodge-Smith and H. P. White.[1] The principal reason for mentioning it here is that in the original description the locality name was inadvertently spelt wrongly as 'Ticraco Creek' instead of 'Tieraco Creek' (26° 20′ S., 118° 20′ E.). Owing to a printer's error the mean width of the kamacite plates is given as 4·08 mm. instead of 0·48 mm., which the context shows to be the correct figure. In the 2-lb. fragment in the Western Australian Museum collection the width varies from 0·2–2·0 mm., with an average of a little over 0·5 mm., placing the iron on the border-line of fine and medium octahedrites. I have detected several inclusions of cohenite in this fragment.

One of the most remarkable features of the meteorite, which is mentioned in the original paper, is the pronounced development of fine octahedral ridges over large areas of the fused crust by differential oxidation of the two nickel-iron alloys during the flight through the air. Where this is most apparent the brownish-black crust is very thin. I have not observed a similar feature on any other Western Australian siderite.

[1] T. H. Smith and H. P. White, Rec. Austr. Mus., 1926, vol. 15, pp. 66–68, pls. II–IV. [Min. Abstr., **3**–258.]

Wonyulgunna.

Siderite (Om), one mass of 83·5 lb. (37·8 kg.), found 1937.

This meteorite was found by an aborigine in June, 1937, on Bald Hill (formerly Wonyulgunna) sheep station, just west of the 485 mile post on the no. 1 rabbit proof fence, and about 21 miles SE. of Mt. Wonyulgunna. The site is 24° 55′ S., 120° 0′ E. The whole mass was recovered by Mr. O. M. Bender and handed to me for examination and subsequent presentation to the Western Australian Museum. It measured $42 \times 29 \times 13$ cm. Two slices have been cut from it, one of 2·1 lb. for the British Museum (Reg. no. 1938,357), one of 9 oz. for the Australian Museum, Sydney.

The chief external characteristics are the very deep pits and bores, the latter, and possibly the former, due to the burning out of troilite cylinders and nodules which are abundantly scattered through the mass. The deepest pit is hemispherical, 8 cm. deep and 7 cm. across the mouth. The numerous bores communicating with the surface range from 0·5 to 2·5 cm. in diameter, and are up to 4 cm. deep. One passes right through the mass. The general appearance of one side of the meteorite is shown in fig. 7, pl. vii. The specific gravity of two pieces was found to be 7·68 and 7·74.

No analysis of the meteorite has been made, but clean filings from the surface of the larger section were found to contain 8·26% of nickel. It would be impossible to obtain any accurate figure for the sulphur content owing to the large size and very irregular distribution of the troilite masses. This is true of most meteorites. An approximate estimate is 1 to 1·5% of sulphur.

Etching reveals a very perfectly crystallized structure, with kamacite plates averaging a centimetre in length and 0·5–2·5 mm. wide, the average about 1·2 mm., placing it at the coarser end of the medium octahedrites (figs. 8 and 9, pl. vii; fig. 10, pl. viii). There are some fairly large interstitial areas of eutectic, one of the largest measuring 7×6 mm. Most of these contain a number of crossing bundles of minute kamacite plates, each plate 0·1 mm. or less in width. There are considerable variations in the arrangement of these secondary kamacite crystals, and the ease with which they can be distinguished. Where most clearly seen, they are arranged in three directions parallel to the primary plates.

Bronze-coloured troilite is abundant, usually as cylindrical masses averaging a centimetre in diameter. One such was found to be enfolded

by a thin layer of schreibersite. The latter mineral is scattered irregularly over the surface with the usual narrow, straight or curved outlines. A prominent feature is the large number of solid masses and tablets of cohenite distributed in groups over the section. These doubtless account for the difficulty in cutting at various stages in the sectioning.

Yalgoo.

Stone (Cw), fragment of 1 lb. 14 oz. (0·85 kg.), known before 1937.

In 1937 the curator found this fragment amongst some other unrecorded specimens in the store-rooms of the Western Australian Museum, where it might easily have lain for twenty years. An attached slip of paper had written on it 'Portion of a meteorite found near Yalgoo', which is at 28° 23′ S., 116° 43′ E. There is no record as to who found it, or when. The meteorite most like it is the Mellenbye (p. 161), which, however, is much darker in colour, and more heavily rusted than this is, and is less rich in nickel-iron.

The Yalgoo stone has a brown fused crust about 0·5 mm. thick. Within this the matrix is greyish-white with small discontinuous brown areas stained with rust. Pale grey chondrules are visible in it. Small specks of clean metal can be seen on a roughly polished face, the specific gravity of the whole mass, 3·42, indicating the presence of about 10% of nickel-iron, thus placing it in Prior's group 3. No analysis or microscopic examination has been made of the stone.

Youanmi.

Siderite (Om), one mass of 261 lb. (118·5 kg.), found 1917.

A brief note recording the discovery of this meteorite was published by the writer[1] in 1918, before any detailed examination of it had been made. It is a single large mass brought to Perth by Inspector of Mines A. W. Winzar from uninhabited granite country about 50 miles south of Youanmi, which would be at 29° 30′ S., 118° 45′ E. He informed me that no marks were left on the surface showing the impact, the surrounding rock being denuded away. This indicates a considerable age for the meteorite. The whole of it, except for two slices of about 1 kg. each, is in the Western Australian Geological Survey collection (no. 1/1436). It measures $19 \times 18 \times 6$ inches ($48 \times 46 \times 16$ cm.).

The surface is fairly deeply and broadly pitted, with several unmistakable bores left by the burning out of troilite, a cylinder of which, two centimetres in diameter, shows in one of the sections (fig. 13, pl. IX).

[1] Ann. Rep. Geol. Surv. W. Austr., 1918, for 1917, pp. 19, 22.

The usual crust of fused haematite and magnetite covers the surface, and some of the latter penetrates into deeply reaching cracks. The iron was fairly easy to cut with a hand hacksaw except for the surface 2 mm. where it was distinctly harder. No cohenite could be seen in the sections. Etching reveals an imperfect crystallization, especially in the hard periphery, with the structure of a medium octahedrite. Some small areas in one slice are quite featureless. For about 2·5 cm. into the interior from one side the kamacite blades are strongly flecked (fig. 14), but on the whole show practically no schiller. They range from 0·5 to 1·5 mm. in width, with an average of 1·0 mm. Schreibersite is not conspicuous, but in one small section is seen as typical graphic forms. An analysis showed:

Fe.	Ni.	Co.	Cu.	Ca,Mg.	Si.	P.	S.	C comb.	C free.	Total.
91·17	8·08	0·87	0·11	nil	0·01	0·15	0·02	0·01	0·04	100·46

Owing to the irregular distribution of troilite as large masses, none of which was included in the analysed material, the figure for sulphur is not characteristic of the whole mass, which probably contains somewhere about 0·5% of this element.

Youndegin III and Mooranoppin II.

With notes on Youndegin I–VIII, Mount Stirling, and Mooranoppin I.

Siderite (Og–Ogg), several large masses, first found 1884.

Amongst the earliest meteorites recorded in Western Australia were Youndegin I–IV (1884), Mount Stirling (1892), and Mooranoppin I (1893). Apparently most of these were originally found by aborigines on the outskirts of settlement at that time, some distance to the east of York, then the nearest town. Different fragments of the one or more falls passed into the hands of various white people.

They were all holosiderites with broad to very broad kamacite lamellae of the classes Og–Ogg, several with one or more ragged edges. All had similar chemical compositions, whilst each contained a notable number of tablets and grains of cohenite, with very little troilite. Four analyses of them are available (p. 167).

The Youndegin meteorite was found, not at the old Youndegin police post, then on the outskirts of civilization, but just north-west of Pikaring Rock,[1] a granite island-hill, 30 miles to the south-east (see map, text-fig. 1). It has become quite famous because of its size and the presence

[1] Mentioned by L. Fletcher (1887) as Penkarring Rock; and this form was used by E. Cohen (1894) and A. Brezina (1896) for the name of the meteorite. On old maps various other spellings appear.—(Ed.)

	Youndegin.		Mt. Stirling.	Mooranoppin I.
	I.	III.		
Fe	92·67	91·67	92·08	90·82
Ni	6·46	7·01	6·72	7·21
Co	0·55	0·93	0·81	0·88
Cu	trace	0·02	nil	nil
Mn	—	nil	nil	nil
Mg	0·42	nil	nil	nil
P	0·24	0·30	0·17	0·42
S	nil	trace	0·06	nil
C combined	—	0·15	0·24	0·67
C free ...	0·04	nil	trace	nil
Si	nil	0·01	0·01	0·01
Total ...	100·38	100·09	100·09	100·01
Analyst ...	L. Fletcher[1]	H. Bowley[2]	H. Bowley[2]	H. Bowley[2]

[1] L. Fletcher, Min. Mag., 1887, vol. 7, p. 125.
[2] E. S. Simpson, Bull. Geol. Surv. W. Austr., 1916, no. 67, p. 136.

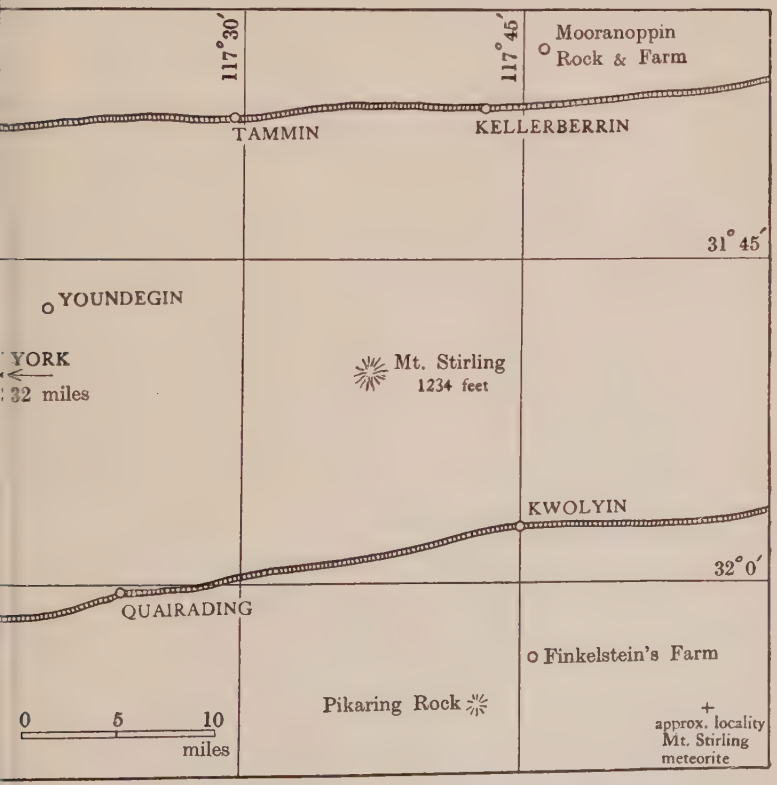

Fig. 1. Sketch-map showing places from which the Youndegin, Mooranoppin, and Mount Stirling meteorites were reported.

in it of cliftonite, a peculiar pseudomorphous form of graphite. In consequence a considerable literature has grown up around it. Originally weighing well over one ton, it apparently burst just before reaching the ground, scattering dozens of fragments over an area of about 10 square miles. Of these the most important pieces found up to the present are:

Youndegin fragments.

Serial no.	Date found.	Finder.	Weight. lb.	kg.	Resting place.
I.	1884	A. Eaton	25¾	11·7	British Museum.
II.	,,	,,	24	10·9	Melbourne Museum.
III.	,,	,,	17½	7·9	Perth Museum.
IV.	,,	,,	6	2·7	British Museum.
V.	1891	L. Knoop	382½	173·5	Ward-Coonley collection.
VI.	1892	,,	2,044	927·0	Vienna Museum.
VII.	1929	— Finkelstein	9	4·1	E. S. Simpson's collection.
VIII.	1891–1929	Knoop and others	30±	14±	Many fragments in private hands.

One piece was made into a horseshoe and hung for many years in a blacksmith's shop at York.

Through the courtesy of the Western Australian Museum Trustees I have been enabled to examine Youndegin III. Three cuts across it were made by means of a circular machine-saw with a blade one-eighth inch thick. The iron, like that of Youndegin I, was very hard to cut, 10 hours being occupied in making the three cuts, each of about 9 square inches. In filing the surfaces, too, the files were rapidly blunted. This hardness was traced to two constitutents, viz. cohenite and a hard, probably carbon-bearing, variety of kamacite forming about one-quarter of the whole. The distribution of the two types of kamacite was rendered visible by the filing. Widmanstetter figures were produced readily by etching with $2E$ HNO_3 (i.e. approx. $2N$ HNO_3) in which some meteorite filings had been dissolved. A very coarse octahedral texture was brought out with plates of kamacite 0·5–6·0 mm. wide possessing a marked schiller (fig. 12, pl. ix). The hard variety of kamacite is in groups of plates of average size. Cohenite is an important constituent, very irregularly distributed as rather thick tablets and ragged grains. Several large inclusions of it are shown in the accompanying figure (fig. 12); one particularly large one, like a hand with index-finger extended, appears on the upper side towards the left. Two long thin slabs of cohenite are just below it, and two other pieces are near the centre of the lower edge. H. Bowley's analysis shows 0·15% of combined carbon in a sample of saw cuttings of Youndegin III, and A. Brezina describes 'ribs of cohenite' in Youndegin VI, though Fletcher found free carbon (clif-

tonite), but no combined carbon, in his analysis of Youndegin I. No cliftonite was observed in Youndegin III, but there was a little graphite in the centre of the largest mass of cohenite. Troilite was not seen in any of the sections of it, nor were any characteristic cavities left on the surface by its burning out. Schreibersite is evenly distributed over the etched surfaces as small irregular plates, usually along the junction of two kamacite lamellae, but at times completely embedded in one. The maximum length and thickness are $5 \times 0{\cdot}5$ mm. H. Bowley's analysis of this fragment of Youndegin III is given above. A minute trace of platinum was detected in it, but no iridium or gold.

Youndegin VII (found on Finkelstein's farm) measures $9 \times 5 \times 3$ inches ($23 \times 12 \times 7{\cdot}5$ cm.). It is deeply eroded and has one long ragged edge where the fragment has been torn from its parent when the pitting had eaten almost entirely through from either side. No characteristic troilite drill holes or hemispherical pits are seen on the surface, nor is troilite exposed in a small section ($6 \times 4{\cdot}5$ cm.). Etching reveals some cohenite, and the very broad plates of schillerized kamacite characteristic of this fall. A damascene structure is seen crossing the kamacite plates; cf. Fletcher's original description of Youndegin I.

The main Mount Stirling meteorite of 200 lb. (90·7 kg.), now in the Sydney Museum, is recorded as having been found 25 miles (probably by cart track) south-east of the mount. Pikaring Rock is 19 miles in a direct line SSE. of Mount Stirling. A second small piece of $14\frac{3}{4}$ oz. (0·42 kg.) was found in the same locality, and is also in the Australian Museum, Sydney. A fragment from the larger piece was analysed by H. Bowley with the results given in the table above. They closely resemble those for Youndegin I and III. Mount Stirling has an octahedral structure with very broad lamellae, 0·5–4·0 mm. Taenite partings are narrow and not usually complete over the whole length of the kamacite blades. Small areas of eutectic are not uncommon. The kamacite plates have a pronounced schiller appearing in a different set at every rotation of 120°. On the polished section of a small specimen in the Western Australian Geological Survey collection, there is no troilite, but three typical masses of cohenite, the largest 5×2 mm. Schreibersite is not plentiful, and lies mostly between the kamacite blades, rarely embedded in them or in the eutectic. The resemblance of this meteorite to Youndegin is very close, and in view of the description given of the locality, there is no doubt that both pieces of Mount Stirling are portions of the Youndegin fall.

Mooranoppin Rock and Farm are 34 miles north of Pikaring Rock,

and it is related that the original Mooranoppin meteorite was brought into the farm about 1893 by an aborigine, who had found it in the unoccupied bush somewhere to the south. It later became part of the Ward-Coonley collection. The resemblance both in structure and composition between it and known parts of Youndegin, strongly suggest that it is another fragment of the same fall. Some very beautiful cohenite is visible in sections of this meteorite (fig. 11, pl. IX). Cohenite is easily recognized by its hardness, brilliant lustre, slightly golden tarnish, and minutely pitted surface produced during polishing owing to its brittleness.

About five years ago the writer was given by the present owner of the Mooranoppin estate, Mr. R. Maitland Leake, a second meteorite, which had been at the homestead for very many years. He believed that it was brought there about the same time and from the same place as Mooranoppin I. This is an angular rhomboid iron, remarkably free from pitting, and completely coated with an unusually thick oxidized crust, fragments of which are still continually flaking off. It weighed 1 lb. 13 oz. (0·82 kg.). This I propose to call Mooranoppin II. On etching a small slice off one end, the kamacite lamellae were found to be very broad (2–4 mm.), whilst cohenite was prominent, and troilite absent. These features serve to link it with Mooranoppin I and the other fragments of the Youndegin fall.

List of Meteorites Recorded from Western Australia.

1892. Ballinoo. Off.
1930. Bencubbin. M.
1923. Dalgaranga. Om.
1932. Dowerin. Siderite.
1930. Gundaring. Og–Ogg.
1894. Hamersley Range (syn. Roebourne). Om.
1937. Kumerina. Of.
1919. Lake Brown. Ci.
1931. Landor. Of.
1932. Mellenbye. Cw.
1921. Milly-Milly. Om.
1893. Mooranoppin. Og–Ogg. Probably part of Youndegin.
1909. Mount Dooling. Om.
1913. Mount Edith. Om.
1916. Mount Magnet (East Mount Magnet). Off–Ogg or Offb.
1892. Mount Stirling. Og–Ogg. Probably part of Youndegin.
1925. Murchison Downs. Of.
1915. Naretha. C.
1902. Nuleri. Om.
1911. Premier Downs. Om.
1922. Tieraco Creek. Of–Om.
1937. Wonyulgunna. Om.
1937. Yalgoo. Cw.
1917. Youanmi. Om.
1884. Youndegin. Og–Ogg.

The dates given are those when the meteorite was seen to fall, or was first found or first known to science.

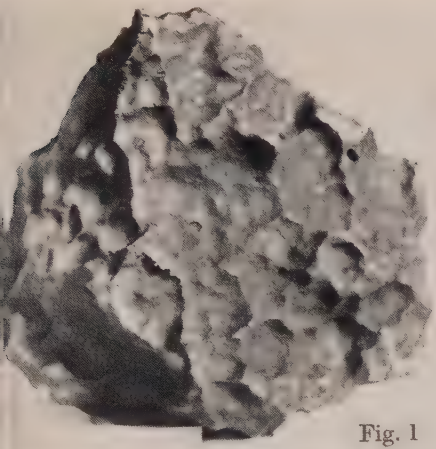

Fig. 1

Fig. 2

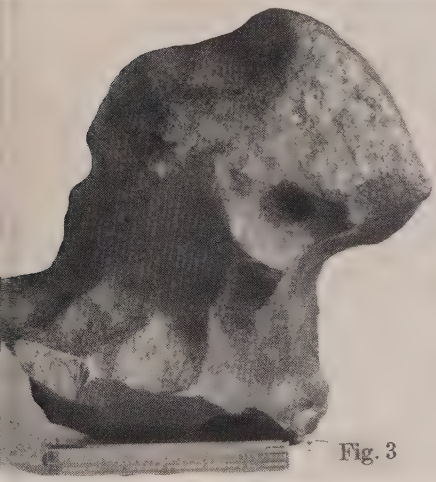

Fig. 3

Fig. 4

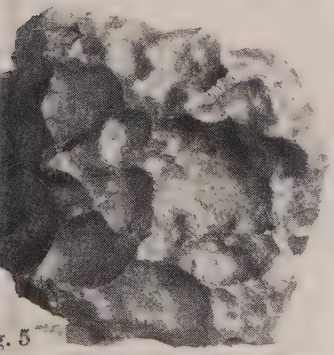

Fig. 5

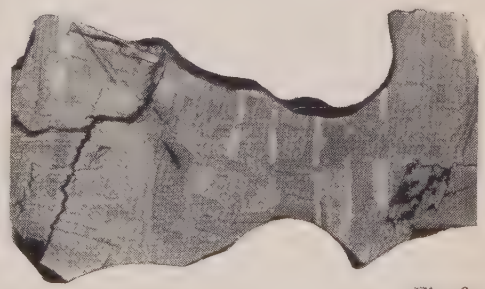

Fig. 6

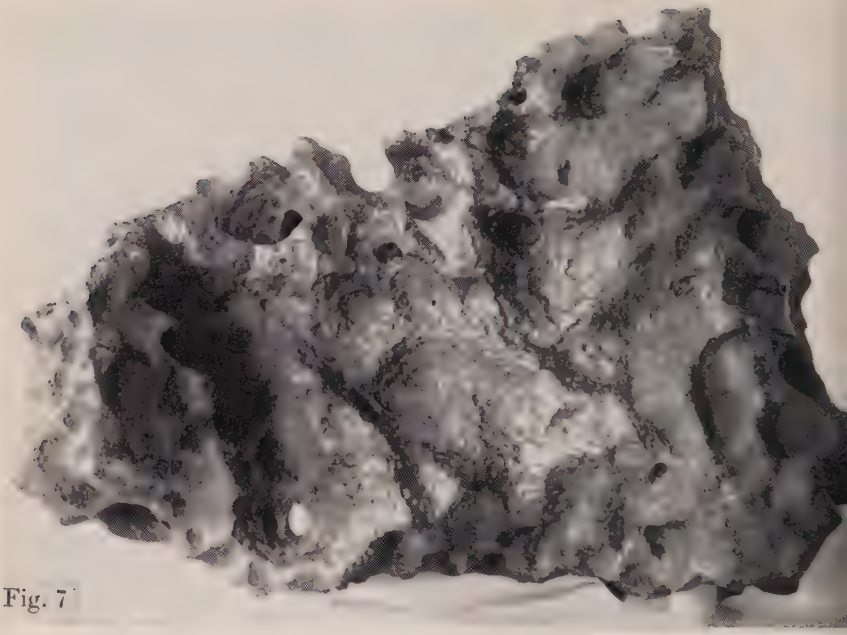

Fig. 7

Fig. 8

Fig. 9

E. S. Simpson: Wonyulgunna Meteorite

Fig. 10

E. S. Simpson: Wonyulgunna Meteorite

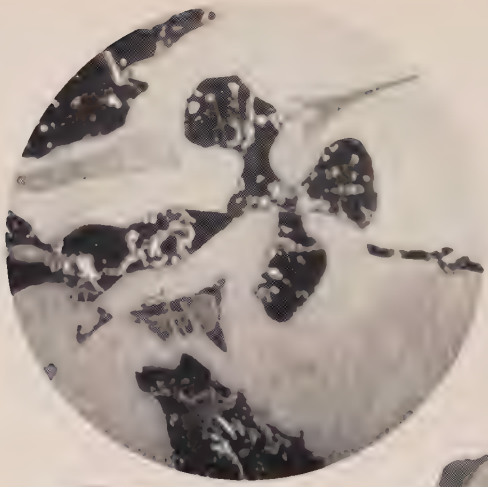

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Explanation of Plates VI–IX.

Western Australian meteorites.

Photographs by E. S. Simpson (figs. 1, 5, 7, 12), F. E. Chapman (figs. 2, 6, 8, 9, 10, 13), B. L. Southern (figs. 3, 4, 14), and H. Bowley (fig. 11).

Plate VI, Fig. 1. Gundaring. Whole mass. $\times \frac{1}{7}$.

— Fig. 2. Gundaring. Etched section, showing regular structure, some large bulbous kamacite, a nodule of troilite, and large areas of eutectic (plessite). $\times \frac{1}{2}$.

— Fig. 3. Kumerina. Whole mass; one end not eroded. $\times \frac{1}{5}$.

— Fig. 4. Kumerina. Etched section. Much of the kamacite is lenticular in form. A mass of cohenite is surrounded by broad kamacite. $\times 13$.

— Fig. 5. Milly-Milly. Whole mass. $\times \frac{1}{5}$.

— Fig. 6. Milly-Milly. Etched section. The kamacite bands show an oriented schiller. $\times \frac{2}{3}$.

Plate VII, Fig. 7. Wonyulgunna. Whole mass, showing tubes (one penetrating the mass) and small deep pits left by burning out of troilite. $\times \frac{2}{7}$.

— Fig. 8. Wonyulgunna. Etched section showing cross-section of rod of troilite. Cohenite is present but not distinctly shown in the photograph. British Museum Collection. $\times \frac{2}{3}$.

— Fig. 9. Wonyulgunna. Etched section. Natural size.

Plate VIII, Fig. 10. Wonyulgunna. Etched section, the same as in fig. 9. Large areas of eutectic (plessite) with small secondary plates of kamacite. Cohenite (black speckled) abundant as slabs, tablets, and grains. Kamacite in places very broad and bulbous (enclosing grains of cohenite). $\times 3$.

Plate IX, Fig. 11. Mooranoppin I. Etched section. Three large masses of cohenite, one club-shaped. $\times 15$.

— Fig. 12. Youndegin III. Etched section. Strong schiller in kamacite. Cohenite; large mass on upper left, two 'ribs' below, and two smaller masses at lower right centre. $\times \frac{3}{4}$.

— Fig. 13. Youanmi. Etched section, with cross-section of rod of troilite. The kamacite pattern shows more distinctly in the photograph than in the specimen. $\times \frac{11}{10}$.

— Fig. 14. Youanmi. Etched section. Flecking of kamacite. Ragged plates of schreibersite. $\times 15$.

The stilpnomelane group of minerals.

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[Read March 10, 1938.]

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Introduction.

WORK which has been in progress during the last few years on the low-grade regionally metamorphosed rocks of western Otago, New Zealand, has shown that members of the stilpnomelane group, hydrous iron- (or manganese-) rich silicates, are exceedingly widespread in rocks with the most varied mineral assemblages. In many cases the mineral in question is in sufficient quantity to rank as an essential constituent and may even be the most abundant one present. Hence in view of the importance of this mineral in the rocks of this region, it was considered that exact analytical data were necessary, and preliminary work in this connexion was carried out by Dr. F. J. Turner and the writer in 1934, but at that time, owing to the difficulties of separation, the pure minerals could not be obtained for analysis.

The present paper includes the results of a petrographical, chemical, and X-ray investigation of stilpnomelane and stilpnomelane-bearing rocks, together with six new analyses of pure stilpnomelanes and seven of rocks. From these data it has been possible to show that the various minerals formerly classed as chalcodite or stilpnomelane really all belong to a series, to be termed the stilpnomelane series, varying between two end-members, the ferrous mineral for which the term ferrostilpnome-

ıe is suggested, and the ferric type for which the name stilpnomelane retained. As will be shown later, it is believed that parsettensite ould be considered the manganiferous member of the group.

Occurrence.

The first occurrence of stilpnomelane in New Zealand was noted by ırner (1934) in quartz-albite-epidote-chlorite-schists from the Forbes ınge, western Otago, but since then this series of minerals has been ınd to occur in each of the four sub-zones of the chlorite zone. Only the Chl. 4 sub-zone, however, is it commonly well crystallized, sometnes forming plates up to 4·0 mm. in diameter which are usually ented parallel to the plane of schistosity of the rocks; when the neral is very abundant it may even form distinct bands consisting nost entirely of stilpnomelane. In some rocks the minerals may occur clusters of radiating plates which lie across the schistosity planes. lpnomelane, with high Fe_2O_3 content, is the most usual member of series occurring in these rocks, while ferrostilpnomelane is much less quently developed, though when present is often abundant.

)f 600 specimens collected from the four sub-zones, stilpnomelanes ırred in 20 %, while in 8–10 % the mineral was in sufficient amount rank as an essential constituent. The mineral assemblages of the rocks which stilpnomelanes have been noted are widely variable, and a list viously published may be conveniently given again, together with litional assemblages observed during this subsequent investigation:

uartz-albite
uartz-muscovite
uartz-chlorite
uartz-garnet
uartz-muscovite-chlorite-garnet
uartz-albite-epidote-chlorite
uartz-albite-epidote-actinolite
uartz-albite-garnet-chlorite-epidote
lbite-epidote-chlorite
lbite-epidote-actinolite
albite-actinolite
albite-epidote-actinolite-chlorite
albite-chlorite-muscovite
chlorite-epidote
chlorite-epidote-magnetite
garnet-calcite
garnet-calcite-chlorite
garnet-pyrite-sphene
magnetite-garnet-actinolite-apatite

The following list shows the percentage of stilpnomelane-bearing ks containing the minerals listed:

uartz	86	magnetite	67	tourmaline	9
lbite	87	muscovite	65	garnet	16
hlorite	86	sphene	52	biotite	4
pidote[1]	94	pyrite	4	calcite	4
ctinolite ...	48	apatite	28	rutile	1

Pumpellyite is very often present together with epidote in the rocks of subes Chl. 1, 2, and 3.

Quartz, albite, chlorite, actinolite, and epidote may occur in important amount, though any one of these constituents may be reduced to the position of accessory or even fail altogether. Muscovite may be an essential mineral, but magnetite and sphene are rarely abundant except in some uncommon schists, viz. sphene-pyrite-garnet-schists and magnetite-garnet-actinolite-apatite-schists. A pale pink or colourless spessartine-garnet is sometimes important, especially in the quartz- and magnetite-schists. It is interesting to note, however, that stilpnomelane though an iron-rich silicate, was rarely found in magnetite-schists. Apart from apatite, the other minerals occur but rarely.

Fig. 1 A. Veinlets of stilpnomelane in garnet-magnetite-stilpnomelane-apatite-schist (no. 3205). One mile west of mouth of Three Mile Creek, Lake Wakatipu.

Fig. 1 B. Coarse red-brown stilpnomelane in albite-stilpnomelane-actinolite-schist (no. 2646). 56 chains east of the junction of Billy Goat Creek and Arrow River, western Otago.

The mineral appears to reach its greatest development in rocks of the green-schist type, i.e. in albite-epidote-chlorite-, albite-epidote-chlorite amphibole-, and albite-epidote-amphibole-schists, for in these types it is usually coarsely crystalloblastic (fig. 1 B) and often very abundant (fig. 2 B). Furthermore, its development may often be important in quartz-schists (fig. 3 B) in which spessartine is often an associated mineral, but generally the plates are not so coarse as in the green-schists. Again, the mineral may be abundantly developed in garnet-calcite- (fig. 2 A) and sphene-pyrite-garnet-schists, but the latter are very rare. In one specimen (no. 3205) of a garnet-amphibole-magnetite-stilpnomelane-

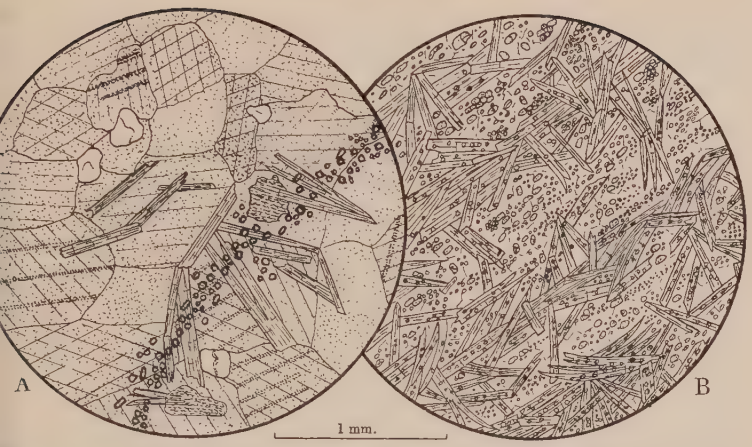

FIG. 2 A. Green ferrostilpnomelane in garnet-calcite-chlorite-ferrostilpnomelane-schist (no. 2702): calcareous band. Templeburn, Arrow Valley, western Otago.
FIG. 2 B. Albite-epidote-stilpnomelane-schist (no. 3230). Trignometrical station mid-Wakatipu survey district, western Otago.

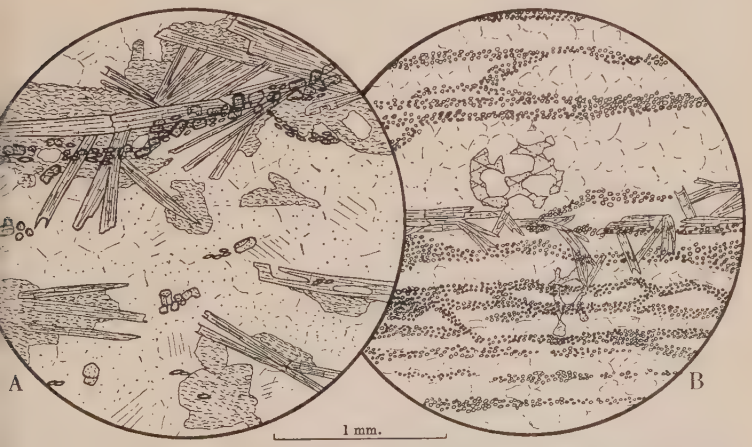

FIG. 3 A. Stilpnomelane developing from chlorite in albite-quartz-epidote-orite-stilpnomelane-schist (no. 2630). Half-mile north-east of Crown Peak, own Range, western Otago.
FIG. 3 B. Band of stilpnomelane in quartz-garnet-stilpnomelane-schist (no. 3202). chains north of Staircase Creek, Lake Wakatipu, western Otago.

hist, the stilpnomelane occurs also as a vein mineral, this being the ly specimen collected showing this feature (fig. 1 A). The writer has o observed stilpnomelane in the incipient stages of formation in a

sheared pyroxenite from the Caples Valley, west of Lake Wakatipu, western Otago (Hutton, 1936, p. 235).

Nomenclature.

Much confusion exists in the specific naming of various members of the stilpnomelane group, the same name in the past having been applied to related but chemically distinct species, while again different terms have been employed for minerals of similar chemical composition. Thus Shannon (1920), followed by Grout and Thiel (1924) and Holzner (1933), terms a member richer in FeO than Fe_2O_3, stilpnomelane, which Genth (1885) and Winchell (1933) designate as chalcodite. On the other hand, this latter term is used by Brush (1858, following Shepard), Fromme (1902), and Shannon (loc. cit.) for minerals with high Fe_2O_3 content, which Hallimond (1924) and Berman (1937) refer to stilpnomelane. Kretschmer (1907) employs the term stilpnomelane for both types.

In order to clarify the situation it is necessary to consider the chemical analyses of the original stilpnomelane and chalcodite. The name stilpnomelane was originally applied by E. F. Glocker (1827) to a shining black mineral occurring at Obergrund near Zuckmantel in Austrian Silesia. Four analyses by Rammelsberg (1838), and one by Siegert (in Rammelsberg, 1853) showed it to be entirely a ferrous mineral, but analyses by the present writer of material from the same locality (see table 3, analyses D and E), which, while indicating total iron to be almost identical with Rammelsberg's FeO figures, gave values in which Fe_2O_3 is greater than FeO. It cannot be argued that the writer's specimens were more oxidized than Rammelsberg's material, for the latter's totals are very low; these, however, can be made to approach a reasonable figure if the total FeO figure is recalculated into FeO and Fe_2O_3 in the ratio found in my analyses. Clearly therefore, the term stilpnomelane must be reserved for minerals of such composition, i.e. in which $Fe_2O_3 > FeO$ (weight per cent.).

Shepard (1852) applied the name chalcodite to a mineral, later analysed by Brush (1858), in which the Fe_2O_3: FeO ratio was almost identical with that in the writer's analyses of the Zuckmantel stilpnomelane. The term chalcodite, having been applied to a mineral whose chemical composition is almost identical with that of stilpnomelane described 25 years before, must therefore disappear.

It seems clear after a study of all the reliable analyses, that any member of the stilpnomelane group (excluding manganese-bearing types) may be considered as a mixture of two end-members, these being

ne minerals characterized by Fe_2O_3 and FeO respectively. For the ormer the name stilpnomelane must be retained and for the latter ne term ferrostilpnomelane is proposed. This may be simplifying the roblem too greatly, but when a number of analyses is considered the ariation in the constituents, other than Fe_2O_3 and FeO, is very small ndeed. It seems quite probable from the X-ray data that parsettensite ould be grouped as a manganiferous stilpnomelane, in which case any nember of this group could be considered as a member of a ternary ystem of stilpnomelane, ferrostilpnomelane, and parsettensite.

Gruner (1937), who recently published chemical and X-ray data on ilpnomelane, states that a division of the stilpnomelane group into erric-rich and ferrous-rich types respectively is untenable on chemical nd structural grounds. While agreeing with the latter, the present riter holds that a division on a chemical basis is both possible and seful; and further it will be shown that there is a variation in the ptical properties with change in chemical composition.

Petrography.

Stilpnomelane, the most abundant constituent in no. 3230 (table 1, nalysis A), forms an intricate criss-cross arrangement of crystals, but radiate grouping of somewhat curving plates is also common (fig. 2 B); clusions of epidote and rarely sphene were noted. Intimate interlamintion with a pale green, optically negative prochlorite is frequent. Albite th a little quartz, as xenoblastic grains with strong undulose extinction, rm 20 % of the rock. Subidioblastic to idioblastic grains of ferriferous idote are quite plentiful and almost entirely constitute some narrow nds. Clusters of granular sphene and pale needles of actinolite, often abbing chlorite, make up the accessories.

Two schists (nos. 2658 and 2692; table 1, anal. B and F) contain plenti-l chlorite in addition to stilpnomelane, the latter forming 25–30 % and –25 % of the rocks respectively. Stilpnomelane forms well-defined ates up to 2·5 mm. in diameter, often in radiate arrangement; intimate ssociation with optically negative chlorite (no. 2692) or negative hlorite and rare muscovite (no. 2658) is noteworthy. Xenoblastic bite, Ab_{98}–Ab_{100}, and epidote are abundant in both specimens. Accesries include quartz, often as 'blebs' in felspar, rare iron-ores, apatite, hene, and slender idioblastic prisms of bluish-green actinolite stabbing ates of chlorite.

No. 2646 (table 1, anal. C) is a coarsely crystalline schist with promint folia of both felspar and stilpnomelane. In thin slice albite is the

TABLE 1. Analyses of stilpnomelane-bearing schists from western Otago, New Zealand. (Analyst, C. O. Hutton.)

	A.	B.	C.	D.	E.	F.	G.
SiO_2 ...	45·96	53·93	61·12	76·33	40·97	48·48	57·66
Al_2O_3 ...	12·80	11·16	14·61	6·96	10·05	11·88	5·00
TiO_2 ...	2·75	2·03	1·00	0·95	0·88	2·47	0·02
Fe_2O_3 ...	13·26	14·07	4·46	2·23	1·34	10·82	21·02
FeO ...	4·73	1·29	1·64	3·35	16·37	5·69	0·67
MnO ...	0·76	0·27	0·13	1·29	4·64	0·23	4·07
MgO ...	4·20	2·86	2·05	2·67	3·38	4·25	1·27
CaO ...	5·79	2·67	2·86	1·20	10·37	7·40	1·80
Na_2O ...	2·37	5·34	9·32	1·55	1·34	3·82	0·11
K_2O ...	0·30	0·66	0·51	0·53	0·58	0·42	0·37
H_2O+ ...	5·77	4·44	1·41	1·92	4·54	3·34	4·87
H_2O- ...	0·86	0·74	0·26	0·18	0·78	0·27	1·35
CO_2 ...	nil	nil	1·02	0·05	4·41	nil	nil
P_2O_5 ...	trace	0·29	0·13	0·18	0·02	0·76	1·43
ZrO_2 ...	nil	nil	nil	nil	trace	nil	nil
Cr_2O_3 ...	nil	nil	nil	trace	nil	trace	nil
BaO ...	nil	nil	nil	nil	nil	nil	nil
(Ni,Co)O ...	—	—	—	—	—	—	nil
FeS_2 ...	0·54	0·31	0·13	0·50	0·24	0·11	0·43
	100·09	100·06	100·65	99·89	99·91	99·94	100·07

Refractive indices of the stilpnomelane mineral in these rocks:

α	1·596	1·615	1·599	1·605	1·551	1·605	1·625
γ	1·686	1·706	1·680	1·690	1·594	1·689	1·735
$\gamma-\alpha$ ...	0·090	0·091	0·081	0·085	0·043	0·084	0·110

A. Albite-epidote-chlorite-stilpnomelane-schist (no. 3230), Trignometrical station H, mid-Wakatipu survey district.

B. Albite-chlorite-stilpnomelane-schist (no. 2658), 800 yards up pack track from Bracken Creek crossing, Arrow Valley.

C. Albite-stilpnomelane-actinolite schist (no. 2646), 56 chains east of the junction of Billy Goat Creek and Arrow River.

D. Quartz-muscovite-garnet-stilpnomelane-schist (no. 2629), 16 chains SE. of Kawarau bridge.

E. Garnet-calcite-chlorite-ferrostilpnomelane-schist (no. 2702), 70 chains up Templeburn from Arrow River.

F. Albite-epidote-chlorite-stilpnomelane-schist (no. 2692), 16 chains SE. of Kawarau bridge.

G. Quartz-garnet-stilpnomelane-schist (no. 3523), one mile from Queenstown along Frankton road, Lake Wakatipu.

most abundant component as rarely twinned xenoblastic grains, often full of inclusions of quartz, sphene, and epidote. Porphyroblastic bluish-green actinolite (2V 65°, $\gamma:c = 16°$) is often intergrown with well-developed coarse stilpnomelane, the plates of which usually lie parallel to the foliation plane, rarely across it. Calcite, quartz, epidote, apatite, and iron-ores are rare.

TABLE 2. Quoted analyses of rocks for comparison with analyses A, C, D, F of stilpnomelane-bearing schists.

		A1.	C1.	D1.	F1.	F2.
SiO_2	...	44·77	60·39	73·71	49·07	50·04
Al_2O_3	...	12·46	18·40	7·25	10·60	11·65
TiO_2	...	5·26	0·80	0·50	—	1·93
Fe_2O_3	...	4·63	1·03	2·63	12·03	2·63
FeO	...	12·99	3·50	0·44	6·57	15·76
MnO	...	0·17	0·08	—	—	—
MgO	...	5·34	1·27	1·47	4·68	5·58
CaO	...	10·20	1·53	1·72	8·58	7·89
Na_2O	...	2·47	8·79	1·19	2·56	3·08
K_2O	...	0·95	0·46	1·00	1·76	0·89
H_2O+	...	0·48	1·37	6·94	1·70	0·19
H_2O-	...	0·12	0·20	2·88	—	—
CO_2	...	0·37	1·70	trace	1·65	—
P_2O_5	...	0·28	0·12	0·24	—	0·20
ZrO_2	...	—	—	—	—	—
Cr_2O_3	...	—	—	—	—	—
FeS_2	...	(S) 0·26	0·02	(SO_3) 0·16	—	—
		100·75	99·66	100·13	99·20	99·84

A1. Gabbro, Lincoln Pond, Essex County, New York. (H.S. Washington's tables, 1917, p. 606.)

C1. Keratophyre, Hanging Rock, Nundle, New South Wales. (W. N. Benson, Proc. Linn. Soc. N.S.W., 1915, vol. 40, p. 139.)

D1. Diatomaceous shale from road near Hollywood Country Club, California. (Analyses of rocks and minerals, 1914–36. Bull. U.S. Geol. Surv., 1937, no. 878, p. 63.)

F1. Diabase, Rio de Janeiro, Brazil. (H.S. Washington's tables, 1917, p. 870.)

F2. Norite, St. Thomas Mount, near Madras, India. (Ibid., 1917, p. 624.)

No. 2629 (table 1, anal. D) is typical of the quartz-rich types, with xenoblastic grains of quartz making up about 75 % of the rock. Muscovite is interleaved with the chlorite from which a little biotite is developing. Stilpnomelane, though not as abundant as in the previous types, occurs as well-developed plates often intimately associated with chlorite and rarely biotite. Colourless idioblastic rhombic-dodecahedra of spessartine-garnet occur in strings and clusters, while spindle-shaped sphene, apatite, and a little iron-ore constitute the accessories.

Stilpnomelane with a composition of approximately $FeSt_{32}St_{68}$ is the most abundant constituent in a quartz-garnet-schist (no. 3523; table 1, anal. G), this rock differing from no. 2629 mainly in the relative proportions of quartz and stilpnomelane. Chlorite, epidote, and iron-ore are rare. Stilpnomelane with a composition close to the ferrostilpnomelane end of the series are also represented in the quartz-garnet-schists (nos. 3186, 3197; see fig. 3 B).

Ferrostilpnomelane, which constitutes at least 40% of no. 2702 (fig. 2 A), imparts to the hand-specimen a lepidoblastic texture. It occurs as sprays of stout plates (up to 3·5 mm. in diameter), sometimes interlaminated with deep-green negative chlorite, and often densely studded with tiny idioblastic garnets and rare epidote. Xenoblastic calcite, often showing multiple twinning and strain effects, is plentiful. Quartz, albite, sphene, and rare magnetite make up the accessories.

Though not analysed, no. 2637, an albite-epidote-chlorite-schist, may be noted here on account of the interesting association in it of well-developed stilpnomelane (α 1·594, γ 1·681) and a member near to ferrostilpnomelane. Both minerals occur as rather coarse radiating plates, lying in the schistosity plane as well as across it; rarely the two minerals are intimately interleaved with one another, but are more commonly interlaminated with a deep-green negative chlorite. A complete gradation from green ferrostilpnomelane to brown stilpnomelane may occasionally be seen. Epidote is plentiful as xenoblastic and idioblastic grains, the iron content of which varies greatly. Accessories include a little actinolite, sphene, quartz, apatite, calcite, and iron-ore.

Stilpnomelane with a composition close to ferrostilpnomelane, spessartine-garnet, pyrite, and sphene are the constituents of a rare and unusual type of schist (no. 3216), which occurs as a narrow band at the junction of some stilpnomelane-bearing albite-epidote-chlorite- and quartzo-felspathic schists. The pyrite occurs as ragged grains more or less elongated in the plane of schistosity, while sphene in clusters of granules as well as a few idioblastic wedge-shaped crystals is important.

Magnetite, stilpnomelane, and manganiferous garnet are the essential components of an interesting schist (no. 3205, fig. 1 A), in which stilpnomelane (γ 1·693), as well as being associated with the other components, occurs as a vein mineral. These veins, varying from 2 to 7 mm. in width, are of two types, in which the mineral (1) has a fibrous aspect, the fibres being oriented perpendicularly to the vein-walls, and (2) is platy and has no obvious orientation. Other minerals include albite, crossite, epidote, sphene, and veins of manganiferous apatite (α 1·632, γ 1·636). Manganese determinations on the schist itself and the vein-forming stilpnomelane gave values: MnO 12·23 % in the rock, and MnO 4·53 % in the vein.

The seven rocks analysed contained members of the stilpnomelane group of minerals as the essential or even the predominant constituents, and their chemical affinities and origin might be briefly considered. In dealing with the latter field relationships should be considered; however,

he nature of the country did not always permit close investigation over ide areas. A occurred in a narrow band, barely one foot wide, closely ssociated with a peculiar ferrostilpnomelane-garnet-pyrite-schist, at r close to the junction of a wide exposure of green-schists and quartzo-elspathic types. B, C, D, and F were associated with green-schists, hile E and G occurred interstratified with quartzo-felspathic rocks.

The schists D and G, with over 50 % of normative quartz, have undoubtedly been derived from impure sandstones. The impurities, which ary in amount in the two rocks, would seem to have been in D mainly me shaly material; while G, on the other hand, containing 25 % of on-ores (in the norm) and high MnO, is not far removed from the mmingtonite-garnet type of schist derived from impure iron-ores.

The remainder of the analyses may be considered together in that ey present certain common features, viz.: (1) FeO and Fe_2O_3 are latively high (except C); (2) MgO and CaO are rather low; and (3) da is high, but potash low. Although analyses A and F are compared th A1 and F1 and F2 respectively (table 2), there are some noteworthy fferences in the bulk composition which should be pointed out. Firstly, e total iron content of A and A1 is very similar, but most of the iron A is in the ferric state while that in A1 is in the ferrous state. Again, ere is a discrepancy in the CaO figures. Thus it may be suggested that e albite-epidote-chlorite-stilpnomelane-schist (analysis A) may have en derived from a doleritic type of rock from which much of the lime as been leached out and which has suffered some oxidation. Analysis F mpares favourably with that of a weathered basic type (analysis F1) nd also with F2, except for the state of oxidation of the iron in the se of F2. B shows a rather high percentage of normative quartz and aematite as well as very low lime and magnesia, features possibly dicating the original unmetamorphosed rock to be a tuff to which a oderate amount of sedimentary detritus had been added. The high nO figure of E excludes direct origin from igneous rock types, but the hist might reasonably be considered a derivative of a highly impure liceous iron-bearing sediment. C shows very high soda and may be mpared with a keratophyritic rock (C1).

In some of the stilpnomelane-schists, ferrostilpnomelane has been bserved to be zoned by a stilpnomelane-rich mineral, indicating an rlier formation of the FeO type. Therefore it is possible that ferro-ilpnomelane has usually formed first, and this by oxidation has given se to the Fe_2O_3-rich types. If this is so, then one must compare only the tal iron content of a rock when making comparisons between analyses.

Optical Properties of the Otago Stilpnomelanes.

Two chemically and optically distinct members of the stilpnomelane group of minerals, viz. minerals near ferrostilpnomelane and stilpnomelane have been observed in the western Otago schists. When well developed they typically occur as thin micaceous plates, often with a radiate or sheaf-like arrangement. Basal sections are always irregular in outline. There is a perfect basal cleavage which is neither quite so regular nor so continuous as in micas, and an imperfect cleavage perpendicular to (001). Colour varies according to the composition from deep green (ferrostilpnomelane) to deep reddish-brown (stilpnomelane). In coarsely crystalloblastic examples in the schists of the Chl. 4 subzone, pleochroism is intense with absorptions according to the following schemes:

Ferrostilpnomelane.	Stilpnomelane.
α = clear pale yellow	α = bright golden-yellow
$\beta = \gamma$ = deep green	$\beta = \gamma$ = deep reddish-brown to nearly black
$\alpha < \beta = \gamma$	$\alpha < \beta = \gamma$

If basal plates of stilpnomelane are 0·05 mm. or more in thickness, basal sections are opaque. A uniaxial figure and a negative optical sign are characteristic, but rarely a biaxial figure has been noted in stilpnomelane. Refractive indices have been determined for a number of examples from Chl. 4 sub-zone schists, and these vary between the following limits: α 1·551—1·625, γ 1·594—1·735, $\gamma - \alpha$ = 0·043—0·110.

The similarity of the stilpnomelane group of minerals with green and brown biotites may be stressed here, and by reason of this it is probable that members of the group are more widely distributed than has hitherto been recognized. However, it is possible to distinguish these two minerals in thin section, and to assist in this the following points are brought forward:

(1) The cleavage in the stilpnomelanes is not so perfect as in biotite.
(2) The stilpnomelanes exhibit an imperfect cleavage perpendicular to (001).
(3) The strong golden-yellow tint for the α vibration-direction in the Fe_2O_3-rich members is characteristic.
(4) In the extinction position there is no mottled effect as is seen in micas.

If it is possible to extract a portion of the mineral from the rock, the following two points will assist in the identification:

(5) Stilpnomelanes are extremely brittle.

(6) Lauegrams of stilpnomelanes are especially characteristic (compare fig. 8 A and B).

Analytical Data.

The preparation of sufficient pure material for mineral analysis was rendered most difficult owing to the extremely brittle nature of the minerals dealt with. On crushing the rock, most of the desired material was reduced to a powder which passed through a 300-mesh sieve together with a good deal of the other minerals. However, by means of careful elutriation, a concentrate was obtained from which the pure mineral was finally only to be obtained by repeated centrifuging with bromoform, bromoform-benzene, and bromoform-methylene iodide mixtures. In all cases this material was then closely inspected under a microscope before analysis.

Analyses of stilpnomelanes from western Otago and type localities, together with their optical data, are given in table 3. Analysis B of pure red-brown stilpnomelane verifies the conclusion previously reached (Turner and Hutton, 1935, p. 3) on the evidence given by a partial analysis of an impure concentrate (table 3, analysis A), that the common type in the western Otago schists has a high Fe_2O_3 and a low FeO content. Comparable analyses may be found in the literature, and a few of these are set down in table 4.

A study of the analyses B to G reveals a number of interesting points. It will be seen that the silica and alumina percentages are fairly constant, but the ratio $FeO:Fe_2O_3$ varies between wide limits. Magnesia may become quite an important constituent, as in B and C, while lime is constantly low. In regard to alkalis, potash, though in small amount, is constantly present, but soda is almost negligible and may be nil. While $H_2O > 105°$ is very constant, the rather high figures for $H_2O < 105°$ are noteworthy. Manganous oxide is important in only two analyses, F and G, and in both these cases the stilpnomelanes occurred in schists containing abundant spessartine-garnet.

Although potash is recorded in most reliable stilpnomelane analyses in the literature, it appears that this constituent may fail altogether (B1, B2, C1, table 4), in which case there does not seem to be any line, at least in chemical nature, between the non-potassic stilpnomelanes on the one hand, and the highly ferruginous serpentines and chlorites on the other.

Eighteen analyses of both biotites and of stilpnomelanes have been plotted on a ternary diagram (fig. 4) to show the relation of the fields

TABLE 3. New analyses of stilpnomelane. (Analyst, C.O. Hutton.)

	A.	B.	C.	D.	E.	F.	G.
SiO_2 ...	49·40	45·24	48·03	44·45	44·67	42·94	44·99
Al_2O_3 ...	6·22	6·73	6·48	7·26	6·83	7·59	6·99
TiO_2 ...	—	0·33	0·23	nil	trace	trace	st. trace
Fe_2O_3 ...	19·22	25·34	4·12	20·82	22·04	21·64	31·67
FeO ...	2·53	3·45	22·88	14·04	13·73	13·23	1·29
(Ni,Co)O	—	trace	—	trace	trace	—	—
MnO ...	—	0·60	2·67	0·05	0·06	0·11	2·57
MgO ...	—	7·67	4·94	2·77	2·33	2·80	2·89
CaO ...	—	1·91	0·83	0·53	0·83	0·91	0·36
Na_2O ...	2·26	0·03	nil	0·03	nil	0·10	0·39
K_2O ...	0·95	1·67	0·83	2·06	1·36	1·91	0·87
H_2O+ ...	—	6·72	6·90	6·41	6·74	6·95	7·94
H_2O- ...	—	0·76	2·64	1·35	1·57	1·94	0·44
Totals ...	80·58	100·45	100·55	99·77	100·16	100·12	100·40
α	1·592	1·599	1·551	1·595	1·595	1·597	1·625
$\beta=\gamma$ ...	1·680	1·680	1·594	1·690	1·685	1·692	1·735
$\gamma-\alpha$ ...	0·088	0·081	0·043	0·095	0·090	0·095	0·110
2V ...	0°	0°	0°	0°	0°	0°	0°
α	bright golden-yellow	bright golden-yellow	pale yellow	pale yellow	pale yellow	pale yellow	bright golden-yellow
$\beta=\gamma$ ...	deep yellowish-brown	deep reddish-brown	deep green	deep olive-brown	deep olive-brown	deep olive-brown	deep reddish-brown
Absorption	$\gamma>\alpha$	$\gamma>\alpha$	$\gamma>\alpha$	$\gamma>\alpha$	$\gamma>\alpha$	$\gamma>\alpha$	$\gamma>\alpha$
Sp. gr. ...	—	2·78	2·62	2·84	2·84	2·85	2·83

A. Stilpnomelane from stilpnomelane-schist (no. 2092); partial analysis only. (F. J. Turner and C. O. Hutton, 1935, p. 3.)

B. Stilpnomelane from albite-stilpnomelane-actinolite-schist (no. 2646), western Otago.

C. Ferrostilpnomelane from garnet-calcite-chlorite-ferrostilpnomelane-schist (no. 2702), western Otago.

D. Stilpnomelane from vein, Zuckmantel, Silesia (no. 1410 in the mineral collection at Cambridge).

E. Stilpnomelane from vein, Zuckmantel, Silesia (no. 1411, ditto).

F. Stilpnomelane, Anna mine, Baern, Moravia.

G. Stilpnomelane from quartz-garnet-schist (no. 3523), western Otago.

of these minerals to one another. If K_2O is considered at the apex of the tetrahedron, it can be seen that the fields will not intersect.

Relationship between Optical Data and Chemical Composition.

In order to show the relationship between chemical composition and optical data, the following points must be brought forward:

(1) There is a change in the colour of the mineral from green to

ABLE 4. Quoted analyses of stilpnomelane and parsettensite for comparison with analyses B, C, E.

	B1.	B2.	C1.	E1.	E2.
SiO_2 ...	44·64	45·12	44·08	43·74	42·90
Al_2O_3 ...	6·75	6·29	4·74	6·36	4·35
TiO_2 ...	—	—	—	nil	n.d.
Fe_2O_3 ...	23·59	23·67	5·27	22·47	0·35
FeO ...	nil	5·93	23·31	15·74	n.d.
MnO ...	—	trace	0·87	0·50	34·43
MgO ...	9·86	9·36	8·36	1·43	2·70
CaO ...	—	trace	trace	0·53	trace
Na_2O ...	—	trace	—	trace	0·20
K_2O ...	—	trace	—	0·75	0·94
H_2O+	7·14	9·12	10·28	6·36	9·66
H_2O-	6·21		2·21	2·59	3·15
Totals ...	98·19	99·49	99·12	100·47	99·27

1. 'Chalcodite' in trap rocks, Westfield, Massachusetts. (E. V. Shannon, 1920.)
2. 'Chalcodite', Lambertville, New Jersey. (E. V. Shannon, Proc. U.S. Nat. Mus., 1920, vol. 58, p. 453.)
3. 'Stilpnomelane' in trap rocks, Westfield, Mass. (E. V. Shannon, 1920.)
4. Stilpnomelane in vein, Pen-y-rallt, North Wales. (A. F. Hallimond, 1924.)
2. Parsettensite, Alp Parsettens, Val d'Err, Graubünden. Also HCl 0·02, CO_2 0·25, V_2O_5 0·32. Sp. gr. 2·590. α 1·546 (clear yellow to colourless), γ 1·576 (light greenish-yellow), $\gamma-\alpha$ 0·030, 2V 0°, negative. (J. Jakob, 1923.)

ep reddish-brown with increase of Fe_2O_3 and concomitant decrease FeO.

(2) An increase in the Fe_2O_3 content causes a rise in the values of α d γ and also in the birefringence. The extreme values are shown in nalyses C and G (table 3).

Unfortunately various authors have not given full optical data with eir analyses, but with the chemical and optical data available it has en possible to construct curves to show the relationship between these roperties; only reliable analyses, however, have been used. It should e emphasized that the α and γ values must be determined on the aterial analysed and not on plates of the mineral obtained from nother part of a large specimen or another specimen altogether. This ppears to be the explanation of many cases in which there is a poor rrespondence of optical and chemical data. The writer has found that, ving to a variation in chemical composition, there can be a difference of much as 0·01 in the values for α and γ in material obtained from fferent parts of the same specimen, if it is a large one. Thus the values r α, β, and γ given by Winchell (1933, p. 435, column 6) for a 'chal-dite' from New York, are clearly not those of a mineral having the

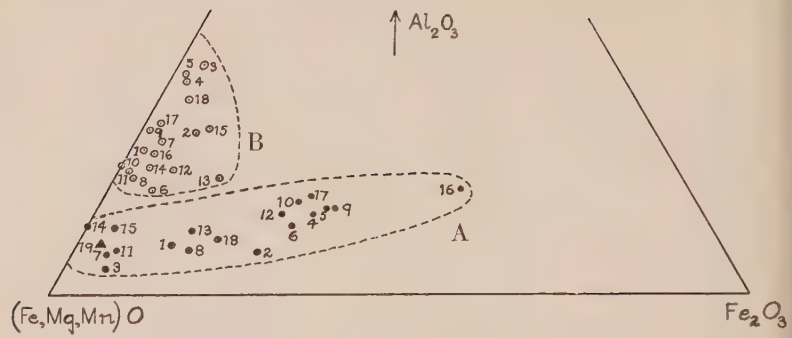

Fig. 4. Plot of analyses of stilpnomelanes and biotites.
A = field of stilpnomelanes; B = field of biotites.

Key to Analyses in Figs. 4 and 5.

Stilpnomelanes.

1. Mesabi Range, Minnesota. F. F. Grout and G. A. Thiel (1924, p. 230, anal. no. 2).
2. Sterling, New York. G. J. Brush (1858).
3. Trap quarries of Westfield, Mass. E. V. Shannon (1920, p. 400, average of anal. nos. 1 and 2).
4. Pen-y-rallt mine, Merionethshire. A. F. Hallimond (1924, p. 194, anal. no. 1).
5. Trap quarries of Westfield, Mass. E. V. Shannon (1920, p. 402, anal. no. 1).
6. Lambertville, New Jersey. E. V. Shannon, Proc. U.S. Nat. Mus., 1920, vol. 58, p. 453, anal. no. 1.
7. Sterling iron mine, New York. F. A. Genth (1886).
8. Theodor mine, Aumenau, Lahn. J. Holzner (1933, p. 216, anal. no. 4).
9. From schist no. 2646, western Otago, New Zealand. C. O. Hutton (anal. B, table 3).
10. Zuckmantel, Austrian Silesia. C. O. Hutton (anal. D, table 3, plotted in fig. 4; and E in fig. 5).
11. Kohlerloche, Harzburg. F. Fromme (1902).
12. Baern, Moravia. J. W. Gruner (1937, p. 913, anal. no. 4).
13. Nadezda mine, Pertniemi, Aunus, Karelia, Russia. P. Eskola (1925, p. 58, anal. no. 1).
14. Recalculated from analysis of 'Schwarzfels'. C. W. Carstens (1924).
15. From schist (no. 2702), western Otago. C. O. Hutton (anal. C, table 3).
16. From schist (no. 3523), western Otago. C. O. Hutton (anal. G, table 3).
17. Anna mine, Baern, Moravia. C. O. Hutton (anal. F, table 3).
18. Mont Chemin, Wallis. J. Jakob, Schweiz. Min. Petr. Mitt., 1927. vol. 7, p. 311.
19. Parsettensite, Alp Parsettens, Val d'Err. J. Jakob (1923, p. 228).

Biotites.

1. Ballochandrian, Cowal, Argyllshire. F. C. Phillips, Min. Mag., 1930, vol. 22, p. 255, anal. no. 7.
2. Hill of Strone, Forfarshire. Ibid., anal. no. 8.

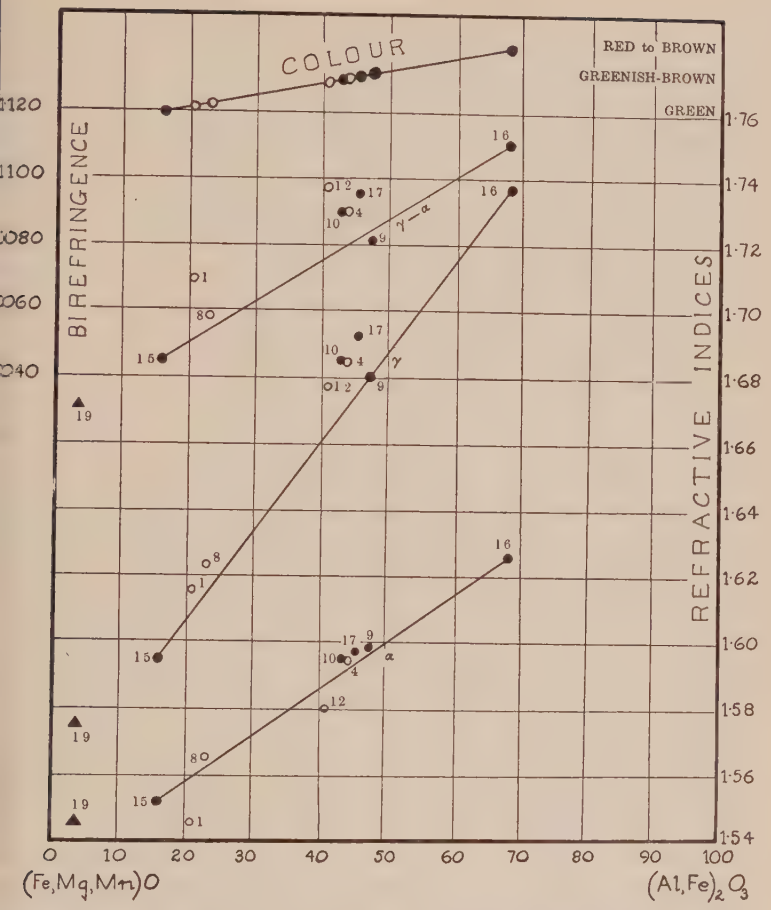

FIG. 5. Variation of optical properties with chemical composition in the stilpnolane group of minerals.

Solid circles: new analyses and optical determinations. Circles: data from the erature. Solid triangle: typical parsettensite (J. Jakob, 1923).

. NE. Forfarshire. Chemical analyses of igneous rocks, metamorphic rocks and minerals. Mem. Geol. Surv. Great Britain, 1931, p. 149, anal. no. 596.
. NE. Forfarshire. Ibid., anal. no. 597.
. De Lank quarry, 2 miles ESE. of St. Tudy, Cornwall. Ibid., anal. no. 598.
. Kekequabic granite, Minnesota. F. F. Grout, Amer. Min., 1924, vol. 9, p. 161, anal. no. 1.
Vermilion granite, Minnesota. Ibid., anal. no. 2.
Quarry north of Mora, Minnesota. Ibid., anal. no. 3.
Rockville, Minnesota. Ibid., anal. no. 4.

KEY TO ANALYSES IN FIG. 4 (*cont.*).

10. Black Cascade, Tripyramid Mountain, New Hampshire. R. W. Chapman and C. R. Williams, Amer. Min., 1935, vol. 20, p. 512, anal. no. 1.
11. One-third of mile NW. of Ames station, Belknap Mountains, New Hampshire. Ibid., anal. no. 2.
12. Quarry one mile south of Beech Hill, Percy quadrangle, New Hampshire. Ibid., anal. no. 3.
13. Brevik, Norway. C. Doelter's Handbuch der Mineralchemie, 1917, vol. 2, pt. 2, p. 698, anal. no. 160.
14. Mt. Hoffmann, California. Ibid., p. 696, anal. no. 141.
15. Felka Valley, Tatra Mts. Ibid., p. 695, anal. no. 126.
16. Osborne's Flat, Yackandandah, Victoria, Australia. C. M. Tattam, Bull. Geol. Surv. Victoria, 1929, no. 52, p. 37, anal. no. 15.
17. Kergunyah Gap, Victoria, Australia. Ibid., anal. no. 16.
18. Noorongong, Victoria, Australia. Ibid., anal. no. 17.

chemical composition stated, and have probably been obtained from a different specimen, though from the same locality as the analysed specimen. Great care must be taken in the determination of the γ value and only the smallest of flakes which are completely translucent must be used. A basal flake of stilpnomelane more than 0·05 mm. in thickness is opaque and the error in the determination of γ in such a specimen may be large. As an example of the variation in composition and optical data, the following values obtained from three specimens of a stilpnomelane from Baern, Moravia, are interesting:

	α.	γ.	$\gamma-\alpha$.	K_2O.
Grout and Thiel (1924)	1·58	1·640	0·060	2·62 %
Gruner (1937)	1·58	1·677	0·097	3·31
Hutton (table 3) ...	1·597	1·692	0·095	1·91

In plotting the values of α, γ, and $\gamma-\alpha$ against (Mg,Fe,Mn)O and $(Al,Fe)_2O_3$ it is found that all the points do not lie exactly on the curves drawn (fig. 5), though it is interesting to note that the values obtained for the three stilpnomelanes separated from the western Otago schists, practically do so (nos. 9, 15, 16). The α value obtained by Grout and Thiel (no. 1) would seem to be much too low for a mineral of that composition. It is clear, however, from a study of the available analyses that the constituents other than Fe_2O_3, Al_2O_3, MgO, FeO, and MnO also vary. For example, $H_2O > 105°$ and K_2O, though not taken into account in these curves, probably have a marked effect on the values for α and γ.

Winchell (1936, p. 644) in his third study of chlorites, states that natural chlorites rich in ferric iron oxidized from ferrous iron have higher refractive indices than that appropriate for their composition;

lso the birefringence increases. The stilpnomelane series as here escribed would appear to bear out Winchell's contention. The artificial xidation of a stilpnomelane was carried out and the data obtained are lso in support of his hypothesis. For this 0·3 gm. of stilpnomelane rom Zuckmantel (specimen no. 1411) was heated in a platinum bucket n an electric furnace for 24 hours at 350° C. An FeO determination hen showed that complete oxidation had taken place and the optical onstants had risen, but the mineral was still uniaxial and negative. he data follow:

	Before heating.	After heating.
FeO ...	13·73 %	nil
Fe_2O_3 ...	22·04 %	37·29 %
α ...	1·595	1·606
γ ...	1·685	1·803
$\gamma-\alpha$ ...	0·090	0·197
α ...	yellow	golden-yellow
γ ...	greenish-brown	reddish-brown

n the diagram (fig. 5) a mineral of this final composition calls for the alues α 1·645, γ 1·780, $\gamma-\alpha$ 0·130. These figures do not agree at all ell with the experimental data, but it must be pointed out that after eing subjected to 350° C. for 24 hours, the mineral has lost 4–5 % of ater of a total of 6–7 %.

The large increase in the values of α and γ obtained in the case of the uckmantel mineral is not in accord with the data obtained by Dschang 931, p. 433) when he artificially oxidized a 'chalcodite' from Bären-ein, Harz. His results were:

	Before heating.	After heating.
FeO ...	10·15 %	0·835 %
Fe_2O_3 ...	31·16 %	42·66 %
γ ...	1·701	1·726

It would be convenient now to consider the mineral parsettensite,[1] hydrous micaceous manganese silicate described by Jakob (1923, p. 227–231) from the Alp Parsettens in the Val d'Err. The analysis 42, table 4) corresponds closely with that of a stilpnomelane with most the iron replaced by manganese and its optical data are very similar a stilpnomelane with an FeO value equivalent to the MnO in the arsettensite. When the values of α, γ, and $\gamma-\alpha$ are plotted against mposition, the points lie almost on the refractive index curves (fig. 5) btained for the ferrostilpnomelane-stilpnomelane series. Further,

[1] The writer wishes to thank Professor J. Jakob for his generous gift of rsettensite.

X-ray work has shown that stilpnomelane and parsettensite are very closely allied.

It has been seen that, when a schist has a high MnO content, the stilpnomelane mineral in that rock also contains considerable MnO, and it is therefore suggested that any stilpnomelane mineral containing manganese may be considered to belong to a ternary system with the components stilpnomelane-ferrostilpnomelane-parsettensite.

Chemical Data and Dehydration.

The stilpnomelanes are slowly dissolved by digesting with $\frac{1}{2}$ *N* hydrochloric acid for eight hours on the water-bath, leaving a residue of colourless plates of silica. The same behaviour was observed with biotite. A warm mixture of dilute H_2SO_4 and HF immediately and vigorously dissolved the minerals.

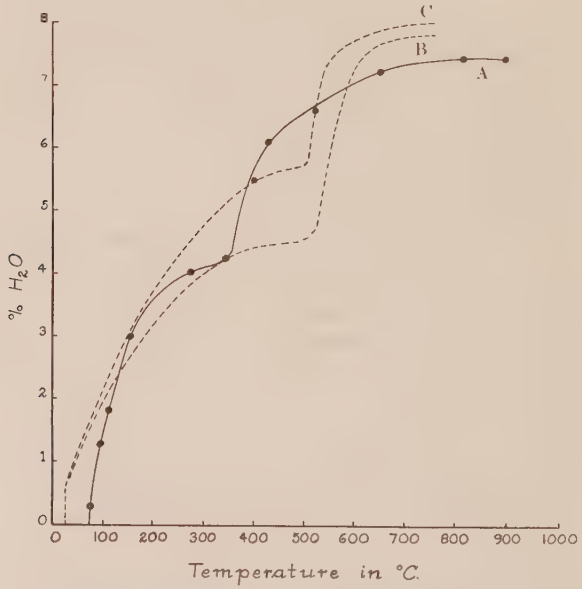

Fig. 6. Dehydration curves of stilpnomelanes.
Curve A determined by the present writer; B and C by Armstrong (Gruner, 1937).

Dehydration of two specimens of stilpnomelane have been carried out by L. C. Armstrong (Gruner, 1937, pp. 915–916) in vacuo with a tensieudiometer, and two curves (B and C in fig. 6), differing somewhat in the region between 300° and 500° C., obtained. The writer, with the

object of obtaining data under different conditions, dehydrated a sample of Zuckmantel stilpnomelane in air in an electric furnace. A series of estimations were subsequently carried out to find the amount of oxidation that had taken place as the mineral was dehydrated. The curve (fig. 6, curve A) obtained by gradual dehydration up to 900° C., though strictly not a true dehydration curve by reason of the oxidation of FeO to Fe_2O_3, does show some similarity with those accurately determined by Anderson in vacuo. The main break in the curve is at 350° C. and, at this point, oxidation was complete. A steep slope is present from 350–425° C., and during this range 2 % of H_2O is given off. Between 800–900° C. no more H_2O remained to be driven off and the mineral was then almost black. In addition to the above experiment, stilpnomelane was placed in a desiccator over pumice soaked in concentrated H_2SO_4, for four months, a loss of weight of 3·04 % being recorded. This weight of water was entirely regained on exposure to the atmosphere for eight hours.

Formula of the Stilpnomelanes.

Hallimond (1924) derived the empirical formula $4(R_2O_3,RO),6SiO_2+aq.$ after consideration of a number of analyses. Berman (1937, p. 383), following Hallimond in separating the minerals of the stilpnomelanes series into two groups, a ferrous and a ferric member, gives them the formulae $(Mg,Fe'')_{13}Al_4Si_{18}O_{50}(OH)_{10}.10H_2O$ and $(Mg,Fe'')(Al,Fe''')_2Si_3O_{10}.H_2O$ respectively. Holzner (1936, p. 447) derived the formula $(Fe,Mg)_2(Fe,Al)_{1\cdot333}[Si_4O_{10}](OH)_4$, but attempts no subdivision. Gruner (1937, p. 914) holds that as 'chalcodite' and stilpnomelane are not different from one another structurally or chemically, except for the oxidation of the iron, any subdivision is untenable. He suggests, after averaging seven analyses and on the results of dehydration and X-ray work, the formula $(OH)_{16}(K,Na,Ca)_{0-2}(Fe,Mg,Al)_{29}Si_{32}O_{93}.13H_2O$. Gruner calculates his formula on the basis of $32SiO_2$ 'molecules' in four unit cells, obtaining the groups $[Si_{32}O_{93}]$, $[(Si,Al)_{16}O_{43}]$, and $[(Si,Al)_{16}O_{42\cdot5}]$; or in an ideal case $[(Si,Al)_{16}O_{44\cdot5}]$. These groupings are not in accord with $[Si_4O_{10}]$, $[AlSi_3O_{10}]$, or $[Si_2Al_2O_{10}]$, which 'represent the contribution of the linked sheets of tetrahedra, whose composition is $n(Si_2O_5)$' universally found in the mica and chlorite minerals (Bragg, 1937, p. 204).

The writer therefore accepts, in part, Holzner's formula, based on the groupings $[Si_4O_{10}]$, but would add to it the ions K and Ca. The structure of stilpnomelane has not yet been completely worked out; therefore the writer, in searching for the most probable formula, has

calculated out a number of analyses on the basis of 12, 14, and 18 (O,OH) atoms to the unit cell; however, from a study of the figures obtained, a value (O,OH) = 14 appears to be most suitable, giving with fair constancy the formula:

$(OH)_4K_{0\cdot33}(Al,Fe,Mg,Mn)_{3\cdot33}Si_4O_{10}$ or $(OH)_{12}K(Al,Fe,Mg,Mn)_{10}Si_{12}O_{30}$.

Aluminium in most cases replaces a little Si to make up the ideal number of 12; Mn in view of its intermediate ionic radius may be spread between the (Fe,Mg) and (K,Ca) groups.

In hornblendes, a replacement of (OH) by O appears to take place along with a replacement of Fe″ by Fe‴, that is, in the analyses of brown basaltic hornblendes the percentage of water is always low (see E. S. Larsen and others, 1937, p. 898). Analyses of stilpnomelanes do not show any variation consistent with this feature, though when calculated on the basis of 14(O,OH) all members of the series give reasonable formulae. Nevertheless, it is clear that extra oxygens will be required in the types with high Fe‴ content. It is suggested that, as Fe‴ replaces Fe″, O replaces (OH), as is postulated in the case of the Fe‴-rich amphiboles. Further dehydration work must be carried out on any stilpnomelane to show the true content of (OH), and it is very probable that the value of this factor will decrease as one passes from the ferro-stilpnomelane to the stilpnomelane end of the series. Thus, for a pure Fe‴ stilpnomelane mineral O will be high while (OH) will be correspondingly low.

As true dehydration curves have not been made for the minerals analysed, all the $H_2O > 105°$ has been included in the calculations and, when necessary, oxygen has been added to the (OH) group to make up the total oxygens in the molecule to 14 (or if multiplying by 3, 42). Nevertheless, from the two dehydration curves given by Gruner (1937, p. 916) it is interesting to note that the percentage of H_2O given off above 500° C. is less in the mineral with the higher amount of Fe_2O_3. Gruner's no. 3 gives off approximately 3 % of H_2O above 500° C., while his no. 4 gives off approximately 2 %. The Fe_2O_3 and FeO values for these specimens are:

	No. 3.	No. 4.
Fe_2O_3 ...	11·60 %	20·79 %
FeO ...	20·00	12·83

Although it is unwise to place too much reliance on results derived from so little data, it is clear that in these two specimens the amount of firmly held water is decidedly less in the more highly oxidized mineral. Therefore, in the formula of a mineral such as no. 4, if the reasoning as

given above is correct, appreciable oxygen would be present replacing the (OH); thus we would have (O_x,OH_y) where $x+y = 12$. The amount of $H_2O > 105°$ in parsettensite, however, is much higher than in stilpnomelanes, and it is possible that a good deal of this is not in the structure of that mineral.

The formulae derived by calculation from several analyses on the basis of 42(O,OH) atoms to the unit cell are set out below.

1.[1] $[O_{2\cdot1}(OH)_{9\cdot9}]K(Fe,Mg,Mn,Ti,Al)_{10}Si_{12}O_{30}$.
4. $[O_{1\cdot1}(OH)_{10\cdot9}](K,Ca)_{0\cdot39}(Fe,Mg,Mn,Al)_{10}(Si,Al)_{12}O_{30}$.
8. $(OH)_{11\cdot6}(K,Na,Ca)_{1\cdot1}(Fe,Mg,Al)_{9\cdot8}(Si,Al)_{12}O_{30}$.
9. $[O_{1\cdot1}(OH)_{10\cdot9}](K,Ca)_{0\cdot99}(Fe,Mg,Mn,Ti,Al)_{9\cdot3}(Si,Al)_{12}O_{30}$.
10. $[O_{1\cdot1}(OH)_{10\cdot9}](K,Ca)_{0\cdot78}(Mg,Fe,Al)_{9\cdot6}(Si,Al)_{12}O_{30}$.
13. $[O_{2\cdot5}(OH)_{9\cdot5}](K,Mn)_{0\cdot97}(Mg,Fe,Mn,Al)_{10}(Si,Al)_{12}O_{30}$.
15. $(OH)_{11\cdot7}(K,Ca)_{0\cdot48}(Mg,Fe,Mn,Ti,Al)_{10}Si_{12\cdot1}O_{30}$.
16. $(OH)_{12\cdot8}(K,Ca,Na,Mn)_{1\cdot05}(Mg,Fe,Al)_8(Si,Al)_{12}O_{30}$.
17. $(OH)_{11\cdot9}(K,Ca,Na)_{0\cdot57}(Mg,Fe,Mn,Al)_{9\cdot3}(Si,Al)_{12}O_{30}$.
18. $(OH)_{12\cdot1}(K,Na)_{0\cdot9}(Mg,Fe,Mn,Ti,Al)_{10}(Si,Al)_{12}O_{30}$.
19. $(OH)_{16\cdot8}(K,Na)_{0\cdot39}(Mn,Fe,Mg,Al)_{9\cdot3}(Si,Al)_{12}O_{30}$.

Origin of the Stilpnomelane Minerals.

Any hypothesis advanced in an attempt to explain the origin of stilpnomelane in the western Otago schists must answer the following facts:

(1) The widespread distribution of members of the group.
(2) Their occurrence in schists of all types of mineral assemblage, except the doubtfully restricted case of the quartz-muscovite-piedmontite-schists.
(3) The occurrence, though rarely, of stilpnomelane as infillings to narrow veins.
(4) The coarse radiate or sheaf-like habit of the flakes and their occasional orientation across planes of foliation.
(5) The apparent development of the mineral from chlorite and the not infrequent occurrence as a border to porphyroblastic grains of magnetite.
(6) The occasional narrow bands of schists in which stilpnomelane minerals form 50 to 80 % of the rock.
(7) The occurrence of the mineral as an accessory constituent in an otherwise normal rock type.
(8) Restriction of the mineral, so far as is at present known, to the rocks of the chlorite zone.

[1] Numbers refer to analyses given in key to figs. 4 and 5 (p. 186).

The usual mode of occurrence of stilpnomelane appears to be as a vein mineral or associated with iron-ore formations. Grout and Thiel (1924), while recording this type of occurrence, have also drawn attention to its widespread development in grey-green carbonate-slates and amphibole-magnetite-slates as radiating or plumose growths, the plates tending to follow the schistosity. They attribute its association with apatite and specularite to high temperature and pressure, but do not suggest any theory as to the origin of the mineral in the slates. Eskola (1925, pp. 56–57) finds the mineral frequently replacing tremolite in copper-bearing veins which cut the greenstones in the Karelia region. Here stilpnomelane itself forms veins in the green-schists and Eskola believes that these schists have been in places 'stilpnomelanized'. If sediments rich in ferrous minerals and poor in potash suffer reconstitution by regional metamorphism, Hallimond (1924) postulates that stilpnomelane minerals rather than biotite will form.

In the case of the schists of Otago only three theories of origin of the stilpnomelane can be advanced:

(1) That we appeal to peculiar initial composition of the rocks in which the stilpnomelanes are developed.

(2) That the stilpnomelane series are truly metamorphic minerals, formed under conditions of temperature and stress characteristic of the chlorite zone.

(3) That the minerals have been formed through the agency of dilute aqueous solutions from a source other than the schists themselves; that is, they are the result of pneumatolysis.

In the region under discussion, surrounding Lake Wakatipu and extending east to Lake Wanaka and west towards Lakes Te Anau and Manapouri, the schists are all characterized by typical chlorite zone assemblages. They have been observed to contain tourmaline which, it is believed, is possibly due to emanations from subjacent granite batholiths. Metallic sulphides such as chalcopyrite, nickeliferous pyrrhotine, arsenopyrite, and stibnite, in addition to numerous barren and auriferous quartz veins, are distributed widely over the area (Hutton, 1934). Thus this region has clearly been affected to a great extent by solutions coming from deep within the crust as well as by the dilute aqueous solutions usually postulated to be abundantly present during a period of dynamothermal metamorphism (Harker, 1932, p. 18).

Let us deal with the hypotheses in turn. Only in a few cases can we consider that initial composition of the original rocks might have been the prime factor in the development of stilpnomelane. Scattered

hroughout the region are narrow bands of schists, usually of rather nusual composition, interbedded with normal quartzose, quartzo-felsathic and green-schists, in which a member of the stilpnomelane group often the most important constituent. Such schists for example are:

stilpnomelane-spessartine-pyrite-sphene
stilpnomelane-spessartine-calcite
stilpnomelane-spessartine-quartz
calcite-chlorite-spessartine-stilpnomelane
magnetite-spessartine-stilpnomelane-actinolite.

Chemically these rocks are similar in containing high iron and manganese oxides, with SiO_2, CaO, and FeS_2 reaching a high figure in individual cases. It is therefore believed that schists with these mineral assemblages have been developed from highly impure bedded iron-ores or perhaps bog-iron-ores, which are notoriously variable in bulk composition, by low-grade dynamothermal metamorphism. Professor Tilley (1936, p. 341), describing eulysites and allied rocks from Ross-shire, notes that Van Bemmelen has found bog-iron-ores containing $FeCO_3$ associated with notable ferric oxide and $MnCO_3$, while Carstens (1924, p. 248) considers bog-iron-ores to be the original material from which 'Schwarzfels' or magnetite-stilpnomelane-rock occurring in the Trondhjem region has developed by metamorphism. It is difficult to conceive a pneumatolytic origin for these schists, particularly when their limited lateral distribution is taken into account.

More difficult of interpretation are those rocks, and they constitute the most usual type of occurrence, in which stilpnomelane is usually an accessory constituent, but may not infrequently rise to the rank of an essential mineral. One cannot appeal in this case to unusual initial composition, for the bulk analysis of normal albite-epidote-chlorite- or quartz-albite-epidote-chlorite-muscovite-schists containing 5 % of well-developed stilpnomelane will not show any particular characteristic which could be construed as being the factor promoting development of stilpnomelane. In sheared greywackes of sub-zone Chl. 1 and 2, stilpnomelane minerals are often present, but the properties of these minerals differ from those present in the equivalent quartz-albite-chlorite-epidote-schists of the Chl. 4 sub-zone in grain-size only. It has been stated previously (Turner and Hutton, 1935, p. 7) that the birefringence of the stilpnomelanes increased with increase of metamorphic grade within the zone of chlorite, but after further study this generalization does not appear to hold good. The stilpnomelanes occurring in Chl. 1, 2, and 3 sub-zone rocks may be the brown ferric-rich types with

high birefringence or varieties close to the ferrostilpnomelane end of the series with correspondingly lower birefringence; greenish-brown intermediate types have also been noted. In schistose rocks of Chl. 1 and 2 sub-zones, tiny platelets of red-brown stilpnomelane may often be interleaved with a very small amount of chlorite, when, except under very high power magnification, an apparent lower birefringence may be observed. The conclusion reached by the inspection of many slices of rocks from the four sub-zones is that the grain-size of the stilpnomelanes definitely increases with increase of metamorphism.

If we are to hold that the stilpnomelane minerals have really crystallized under chlorite zone metamorphic conditions, in what manner are we to explain their occurrence in one albite-epidote-chlorite-schist of normal mineralogical composition and not in another with a similar composition? If pneumatolytic solutions had been active enough to cause crystallization of stilpnomelane it would be expected that other signs of such a factor would be in evidence, but this is not the case. In the writer's opinion (and if this be true), the solutions and vapours given off from the granitic batholiths situated in the deep zones of this region, although they have caused development of tourmaline throughout the schist area, cannot be held to have in any way assisted in the formation of stilpnomelane. It might be argued that the increase in grain-size of the stilpnomelane minerals with increase of metamorphic grade was evidence that these granitic vapours did play some role; that is, the deeper zones (higher metamorphic grade) were more affected, and hence larger crystals were produced, while the poorly schistose greywackes of the upper zones were but slightly affected, development therefore being restricted. If this held, then one would expect to find tourmaline very much more abundant in the higher grade rocks than in the lower, but this does not appear to be the case. Hence the physico-chemical conditions prevailing in the chlorite zone during dynamo-thermal metamorphism must be held to be the prime factor in the development of stilpnomelane. Under such conditions the chemical composition of the aqueous solutions within the rocks does in all probability vary greatly, producing in one locality an environment suitable for the formation of stilpnomelanes, and in another locality conditions under which they would not be stable.

However, this mode of origin does not necessarily explain various other features of the occurrence of stilpnomelane:

(1) The habit of the mineral when it forms coarse sheaf-like aggregates lying across the foliation planes.

(2) The partial rejoining of stilpnomelane-rich bands which have been cut by quartzo-felspathic veinlets.

(3) The occurrence of sharply crystallized stilpnomelane within micro-folds and contortions, the mineral itself showing no sign of distortion.

(4) The crystallization of the mineral in what appears to have been open fissure veins.

Stilpnomelane belonging to the above categories is free from the ects of any stress during crystallization and does undoubtedly belong

IG. 7 A. Development of stilpnomelane as tufts in Chl. 2 sub-zone greywacke 3239), near Mount Nicholas station wharf, on shore of Lake Wakatipu, west-Otago.

IG. 7 B. Development of stilpnomelane from chlorite in albite-epidote-chlorite-st (no. 2642). Half-mile NW. of Crown Peak, Crown Range, western Otago.

a period of post-tectonic crystallization. Its development thus sug-s a process of segregation by solutions. In the stilpnomelane occupy-veins there certainly is a correspondence between the chemical nature he mineral and that of the rock, which would not be expected should origin be attributed to solutions from some external source. Segre-on veins of other minerals, such as quartz, albite, and epidote, are uncommon throughout the entire region. The other modes of urrence noted above are believed to be merely a recrystallization, aps in places of least pressure in response to the Riecke principle, r complete cessation of movement.

We have yet to consider the chemical reactions involved in the

production of stilpnomelane in chemically normal schists of this region Clearly a lack of potash is not an essential condition, for stilpnomelan may be abundantly developed in rocks fairly rich in muscovite. I most cases the mineral certainly develops from chlorite (fig. 3 A; fig. A and B), but in a few instances stilpnomelane and chlorite appear t have crystallized independently of one another.

As development from chlorite is the most usual feature, the chemica composition of the groundmass chlorites and stilpnomelanes must b compared; two groundmass chlorites have been separated and analyse and these analyses are compared with those of two stilpnomelanes i table 5.

TABLE 5. Analyses of chlorites from Otago, New Zealand, compared with those o stilpnomelane.

	A.	B.	C.	D.
SiO_2 ...	25.62	26·69	48·03	45·24
Al_2O_3 ...	21·19	19·57	6·48	6·73
TiO_2 ...	0·88	0·30	0·23	0·33
Cr_2O_3 ...	trace	nil	—	—
Fe_2O_3 ...	3·88	3·49	4·12	25·34
FeO ...	21·55	21·80	22·88	3·45
NiO ...	nil	0·13	—	—
MnO ...	0·35	0·30	2·67	0·60
MgO ...	15·28	16·23	4·94	7·67
CaO ...	0·16	0·17	0·83	1·91
Na_2O ...	nil	trace	nil	0·03
K_2O ...	nil	trace	0·83	1·67
H_2O+ ...	10·87	11·19	6·90	6·72
H_2O- ...	0·19	0·12	2·64	0·76
Totals ...	99·97	99·99	100·55	100·45
Sp. gr. ...	2·96	2·96	2·62	2·78

	$\alpha = \beta$.	γ.	$\gamma - \alpha$.	Absorption.	2V.	Sign.
A ...	1·622 clear green	1·626 pale yellow	0·004	$\alpha = \beta > \gamma$	0°	+
B ...	1·623 clear green	1·625 pale yellow	0·002	$\alpha = \beta > \gamma$	0°	+

A. Chlorite from albite-chlorite-schist (no. 2586), alongside Springburn serpentin outcrop, Kawarau survey district, western Otago. Analyst, C. O. Hutton.

B. Chlorite from albite-epidote-chlorite-actinolite-calcite-schist (no. 2718), summi of Coronet Peak, Wakatipu region, western Otago. Analyst, C. O. Hutton.

C. Stilpnomelane, table 3, analysis C.

D. Stilpnomelane, table 3, analysis B.

The analyses A and B are recalculated below on the basis of 18(O,OH) atoms t the unit cell.

	A.				B.			
...	25·62	2·692			26·69	2·790		
			1·308	4·00			1·210	4·00
...	21·19	2·610			19·57	2·396		
			1·302				1·186	
...	0·88	0·063			0·30	0·025		
...	3·88	0·302			3·49	0·263		
...	21·55	1·885		5·99	21·80	1·900		5·95
...	—	—			0·13	0·013		
...	0·35	0·031			0·30	0·025		
...	15·28	2·408			16·23	2·539		
-	10·87	7·602		7·60	11·19	7·810		7·81

Formula (A):—$(OH)_{7\cdot6}(Mg,Fe,Al,Ti,Mn)_6(Al,Si)_4O_{10}$.
Formula (B):—$(OH)_{7\cdot8}(Mg,Fe,Al,Ti,Mn,Ni)_6(Al,Si)_4O_{10}$.

fractive index determinations of numerous other chlorites in the ern Otago schists indicate that the typical chlorites found in these are highly aluminous and rich in iron; such chlorites lie either in eld of ripidolites in Winchell's diagram (1936, p. 649) or with change n in the diabantite field. The production of a stilpnomelane of osition C (table 5) from a chlorite of composition such as A or B ves addition of silica and in some cases iron oxides, with subtraction mina and some magnesia. Iron oxides may come from iron-ores, n additional source of iron may be obtained from the ferruginous tes, which show a tendency to change over to clinozoisitic types rejection of iron-ore as metamorphism of the schists becomes more e. Thus, if iron is thrown out from epidote, the aluminium freed e chlorite → stilpnomelane reaction will be taken up by it to form linozoisite molecule. Excess MgO might readily assist together with te or calcite in the production of actinolitic amphiboles or even biotite in green-schists approaching the biotite isograd.[1] In this exion it should be pointed out that 65 % of the schists in which omelane is more or less an important constituent, but excluding rocks of peculiar initial composition in which it is abundant, olite or actinolitic amphiboles are present. Nevertheless, it is considered necessary that MgO should remain in the immediate bourhood of the reaction as postulated above, but would in cases migrate together with other substances, assisting in the opment of amphiboles elsewhere. The small amount of K_2O is usually present in stilpnomelane minerals might readily be ied by the aqueous solutions in the rocks or from muscovite

must be pointed out, however, that there is no direct evidence that these ons do take place, though in Chl. 2 sub-zone rocks tufts of stilpnomelane have observed closely associated with actinolite forming from relics of hornblende.

itself. In the case of stilpnomelane forming rims to magnetite porphyr blasts, a reaction between the iron-ore and the rock solutions may envisaged.

The reactions which are considered to bring about development stilpnomelane are given in diagrammatic form below:

(1) $(OH)_8(Mg,Fe,Al)_6(Al,Si)_4O_{10}+SiO_2+K_2O \rightarrow$ stilpnomelane $+MgO+Al_2O_3$.
(2) $2(OH)Ca_2(Al,Fe)_3Si_3O_{12}+3Al_2O_3 \rightarrow 2(OH)Ca_2Al_3Si_3O_{12}+3Fe_2O_3$.
(3) Epidote (?) (or calcite) $+MgO+SiO_2 \rightarrow$ actinolite or biotite.

The production of a ferrostilpnomelane has alone been considere but by far the most important members of the series in the schists a the red-brown ferric types. In several schists the transition of the gree mineral to the red has been noted, a feature pointing to the earlier d velopment of the green or FeO variety, which with subsequent oxidatic passes into the typical red-brown type.

If stilpnomelane minerals develop by a normal process of dynam thermal metamorphism over wide tracts of country, why has its presen not been recorded from other areas, such as the Dalradian successic in Scotland, where rocks similar to those in western Otago are exposed Two reasons may be suggested for this:

(1) That on account of the close similarity with biotite it has bee dismissed as such. The writer has examined thin slices of metamo phosed spilites, porphyry breccias, and diabases from the Tayvallic Peninsula and Castle Sween across Loch Sween, and recognized in the typical red-brown stilpnomelane as well as a greenish-brown bioti abundantly developing at the expense of the chlorite. The stilpnomela is well crystallized, often as radiating sprays, and in a felspar-porphyr from Castle Sween (no. 30453)[1] with checker-albites, it is the only oth important constituent. In the Geological Survey Memoir on this are Flett (1911, p. 89) has described well-crystallized, clear brown an yellow-brown 'biotites' in epidiorites from Eilean Traighe. From th colour given this 'brown biotite' is very possibly stilpnomelane, for th usual colour of the mica in these rocks is a rather deep brownish-gree Again (1911, p. 77) he describes a rich brown mica in long needle-lik pointed forms suggesting aegirine; likewise this may be a Fe_2O_3 type stilpnomelane mineral. Further, Wiseman (1934, p. 376) has recorded golden-brown mineral with γ 1·758, which he believes to be stilpnom lane, in a low-grade epidiorite from Cnoc-na-Faire, north of Tayvallic An examination of this rock proves that the mineral is definitely stil

[1] The number refers to a section in the Harker Collection in the Department Mineralogy and Petrology, Cambridge.

elane. Thus it seems probable that members of this group of minerals be far more widespread than is at present recognized.

) After a cursory examination of a number of slices of well-crystal- l chlorite zone schists from the Scottish Highlands, the writer feels on the average the grain-size of equivalent schists from western go is decidedly greater. The interpretation of this feature is not r, but the tentative theory might be advanced that chlorite zone litions of temperature and pressure were held at a maximum for ıch longer period in the case of the western Otago schists with the ltant production of larger crystal grains. If this interpretation be ptable, the widespread production of stilpnomelane might conceiv- have been in some measure assisted by these long sustained ımorphic conditions.

study of higher grade rocks than the chlorite zone by Turner (1933) not shown stilpnomelane to be represented among the mineral ıblages. The writer hopes to be able to follow up this phase of the at a later date.

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RAY INVESTIGATION OF THE STILPNOMELANE GROUP OF MINERALS.

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order to determine the symmetry and cell dimensions of endbers of the stilpnomelane group of minerals, Lauegrams, singleal, and powder photographs were taken. The material employed ostilpnomelane and stilpnomelane) was obtained from western o schists in which the flakes of these minerals are small; and, owing e extremely brittle nature of these minerals, preparation of suitable rial was somewhat difficult.

r each mineral species, three single-crystal 15° oscillation photoıs were taken: (1) with the flake vertical and the X-rays passing ugh the crystal parallel to the *c*-axis; (2) with the flake vertical but d through 90° from the first position, in order to observe reflections the planes parallel to the surface of the flake; (3) with the flake ontal and the X-rays passing along the *a* or *b* orthohexagonal axes. tered iron and cobalt radiations were used, but the iron proved more

satisfactory, on account of the ferriferous nature of the minerals investigated and also the large cell dimensions. The use of the longer wave-length iron radiation permitted of somewhat more accurate spacing determinations. Indexing of the films was carried out by means of a Bernal chart (Bernal, 1926).

The only direct X-ray investigation previously carried out on the stilpnomelane group of minerals is the recent work of Gruner (1937), who based all his observations on powder photographs. It is somewhat surprising that his material did not afford single crystals large enough for oscillation or Weissenberg photographs seeing that some of it came from Baern, Moravia. On the evidence of powder photographs Gruner (1937, p. 924) obtained the following cell dimensions, assuming that the mineral is monoclinic (pseudo-hexagonal): a 5·23—5·27, b 9·08—9·12 c 12·07—12·18 Å. The c-spacing was obtained from measurements on the powder photographs, but the length of the a-axis was deduced simply from an apparent similarity with biotite. (On account of the pseudo-hexagonal nature of the lattice, $b = \sqrt{3}\,a$.)

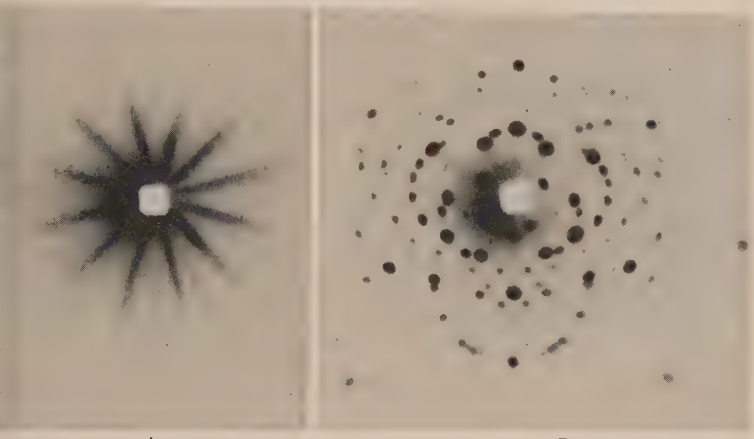
The Lauegrams obtained from members of the stilpnomelane group of minerals are most interesting, but unusual in that true spots were not obtained; instead, all photographs showed almost complete asterism with 6-fold symmetry (fig. 8 A). In order to determine if other minerals characterized by flaky structure, easy cleavage, and pseudo-hexagonal symmetry, that is, minerals based on sheets of linked silicon-oxygen tetrahedra, produced this effect, Lauegrams were taken of a number of minerals. Of these minerals, phlogopite, biotite (fig. 8 B), muscovite and brucite produced Lauegrams with sharp spots, while pennine and clinochlore gave sharp spots as well as faint streaks. Talc and chloritoid showed marked asterism with poor development of spots, while pyrophyllite and the three members of the stilpnomelane group showed almost perfect asterism.

The cell dimensions deduced from single-crystal oscillation photographs are:

	Orthohexagonal			Rhombohedral	
	a.	b.	c.	a.	angle.
Stilpnomelane	22·0	38·0	37·9	17·9	76°
Ferrostilpnomelane ...	22·1	38·1	36·2	17·6	78°
Parsettensite	22·5	39·0	38·0	—	—

The Lauegrams (fig. 8 A) suggest that the three end-members of the stilpnomelane group of minerals are either hexagonal or rhombohedral. The single-crystal oscillation films confirm this suggestion. The photo

raphs obtained by mounting the specimens about an axis in the *c*-plane ith the X-rays perpendicular to that plane and oscillating 15° from at position are rather unusual (figs. 9 A and B). They are characterized (1) the large number of closely spaced, comparatively weak reflections hich indicate that the unit cells are very large, and (2) the presence three very intense reflections in stilpnomelane and ferrostilpnomelane ad six in parsettensite, of spacing 2·6 Å.

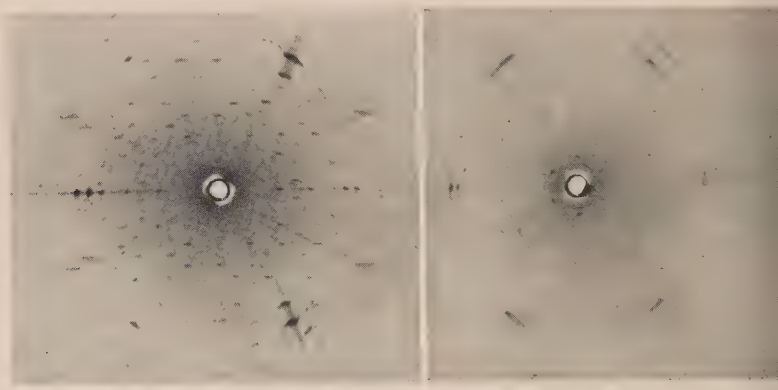


A B

FIG. 8 A. Lauegram of stilpnomelane from Baern, Moravia.
FIG. 8 B. Lauegram of biotite.

These observations suggest that all three minerals possess structures at are essentially a packing of somewhat distorted mica-like sheets. a mica-like sheet we mean an extended double layer of linked SiO_4 rahedra whose vertices point inwards. The interstices between the o component layers are filled with metallic ions, usually Al, Mg, Fe. The sheets possess hexagonal symmetry, but they are most nveniently referred to orthogonal axes, in which case the units are tangular 5·2×9·0 Å. (Bragg, 1937, pp. 143 and 206). The thickness the sheets, that is, the distance between the planes passing through e centres of the external oxygen atoms is 6·6 Å. In all three minerals, e packing of the sheets repeats every third layer. In stilpnomelane d ferrostilpnomelane two observations suggest that the packing of the eets is rhombohedral: (*a*) the reflections from the basal plane occur ly for $l = 3n$; (*b*) in *c*-axis oscillation films, on any given row-line, lections occur only on every third layer-line. In parsettensite con- ion (*a*) is fulfilled. The *c*-axis oscillation photograph is not very good,

but it appears that while on any given row-line every third reflection is intense, yet some very faint intermediate reflections occur. Also the oscillation film (fig. 9 B) has six intense reflections, while stilpnomelane and ferrostilpnomelane have only three. Parsettensite, therefore, is probably hexagonal with marked pseudo-rhombohedral arrangement of the layers.



A B

FIG. 9 A. X-ray oscillation photograph of stilpnomelane from schist no. 2646 western Otago, New Zealand.

FIG. 9 B. X-ray oscillation photograph of parsettensite from Alp Parsettens Switzerland.

The structure of the layers is interesting. As a first approximation they may be considered, by analogy with other minerals, as a packing of rectangular mica units 9×5 Å. in size, with distortion and disorientation, and possibly variations in the sub-units, resulting in the presence of a two-dimensional super-lattice. The reflections due to the super-lattice are very weak (figs. 9 A and B) and it is easy to see why Gruner using powder methods, failed to observe them.

In each case the two-dimensional super-lattice unit, that is, the true unit referred to the orthohexagonal axes in the sheets, contains sixteen rectangular mica units of dimensions a 5, b 9 Å. From the X-ray films (figs. 9 A and B) it can be inferred that in stilpnomelane and ferrostilpnomelane, the a- and b-axes are parallel respectively to the a- and b-axes of the sub-units, while in parsettensite they are respectively perpendicular. The c-axes are too long to be due to three layer-structures of mica sheets alone. The structure is probably like chlorite in consisting of an interleaved structure of alternate distorted mica sheets and layers containing K, OH, and Mg.

The character of the reflections suggests a possible explanation of the asterism in the Laue photographs. The intense sub-lattice reflections are spread out along Debye-Scherrer curves. This indicates some disorientation of the sub-units. The weak super-lattice spots in the *c*-axis oscillation photographs show smearing along the direction of the rowlines. Such effects could be produced by lack of perfect regularity in the packing of the sub-units. The 16 sub-units which compose the unit cell are not identical and it is possible that the arrangement of the sub-units varies somewhat from cell to cell. This would produce reflections smeared in the direction of the *c*-axis, and in the case of the Laue photographs asterism would result. A complete determination must await a more detailed analysis of the intensities of the X-ray reflections.

We are greatly indebted to Professor J. D. Bernal for his interest and advice.

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A chemical and optical study of a low-grade metamorphic actinolitic amphibole from Coronet Peak, western Otago, New Zealand.

By C. Osborne Hutton, M.Sc., Ph.D., F.G.S.
Shirtcliffe Fellow of the University of New Zealand.
Department of Mineralogy and Petrology, University of Cambridge.

[Read June 9, 1938.]

THIS amphibole is an important constituent of an albite-epidote-actinolite-chlorite-calcite-schist[1] from the summit of Coronet Peak in the Wakatipu district, western Otago. The mineral is somewhat concentrated into folia and porphyroblastic crystals up to 5·0 mm. in length, and is markedly flattened parallel to the orthopinakoid so that sections cut parallel to the schistosity exhibit numerous porphyroblasts, deeply coloured, poorly birefringent, and showing rather poor cleavage lines (fig. 1 A and B; fig. 2 A). In slices cut across the foliation numerous elongated end-sections are to be seen with development of small orthopinakoids (fig. 2 B).

The refractive indices ($\pm 0{\cdot}002$) are α 1·635, β 1·650, γ 1·655; $\gamma - \alpha$ 0·020. The angle $\gamma : c = 18°$, and 2V $60° \pm 1°$. Pleochroism follows the scheme α pale yellow, β dirty bluish-green, γ deep bluish-green, with absorption $\gamma > \beta > \alpha$.

It was found that some sections nearly, but not quite, parallel to (100), and especially sections very nearly normal to the acute bisectrix of the optic axes, gave wide extinction-angles, in some cases up to 34°, from the crystallographic axis c; and in order to determine the true angle between γ of the refractive index ellipsoid and the c-axis, a series of extinction-angles in the prism-zone was determined on the universal stage. The curve (fig. 3) shows a rapid rise in the value $\gamma : c$ to 22° at only 30° from (100), and then a gentle slope down to 18° on the clinopinakoid.[2] Using the values 2V 60° and $\gamma : c$ 18°, theoretical values for the extinction-angles in the prism-zone were calculated stereographically, and the determined values when plotted give a curve corresponding very closely

[1] No. 2718 in the rock section collection, University of Otago.

[2] It is interesting to note that cleavage plates of this amphibole give high extinction-angles, very close to the maximum value obtainable in the prism-zone.

indeed to that experimentally obtained. Stereographically, it is possible to show that sections cut nearly normal to the acute bisectrix of the optic axes exhibit angles as high as 35°.

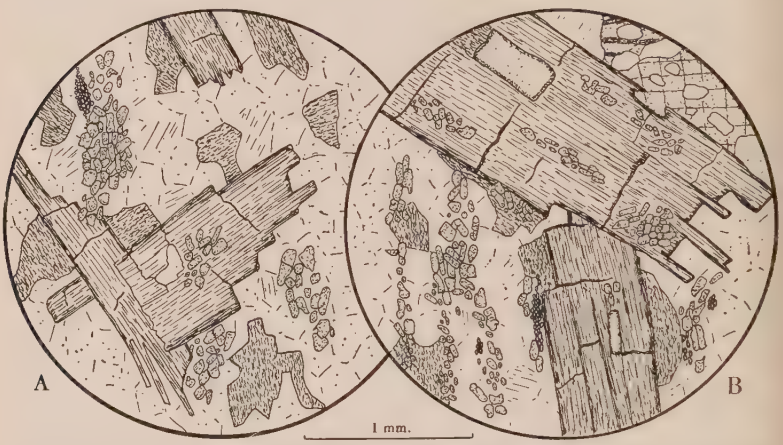

Fig. 1 A and B. Porphyroblastic actinolite in albite-epidote-actinolite-chlorite-calcite-schist (no. 2718); section cut parallel to the plane of schistosity. From Coronet Peak, western Otago, New Zealand.

That the maximum extinction-angle in the prism-zone in amphiboles may be in some other plane than (010) is not a new feature, but has been clearly demonstrated by R. A. Daly,[1] though he stresses the fact that this feature is not believed to be true by many writers. Likewise Rosenbusch and Wülfing[2] show by means of graphs the extinction-angles obtainable in any position in the prism-zone with various values of 2V and $\gamma:c$; from these graphs it is clear that in some cases the maximum extinction-angles in the prism-zone is not always to be found on (010).

The Coronet Peak amphibole was separated in the pure state by the use of the centrifuge and the analysis is given below, together with the structural formula calculated on the basis of 24(O,OH,F) atoms per unit cell. Several points may be noted in the analysis of this amphibole: firstly, the low aluminium figure, most of which replaces silicon in order to make up the ideal Si figure; secondly, magnesia is greater than iron; thirdly, soda is rather high, while K_2O is very low; fourthly, the analysis

[1] R. A. Daly, On the optical characters of the vertical zone of amphiboles and pyroxenes: and on a new method of determining the extinction angles of these minerals by means of cleavage pieces. Proc. Amer. Acad. Arts and Sci., 1899, vol. 34, pp. 311–323; and Bull. Soc. Franç. Min., 1899, vol. 22, pp. 161–174.

[2] H. Rosenbusch and E. A. Wülfing, Mikroskopische Physiographie. 1924, vol. 1, part 1, pp. 490–491.

fits the formula of tremolite as worked out by Warren[1] from X-ray data. The alkali group, however, does not exceed 2, therefore as Warren suggested the AA′ position remains vacant.

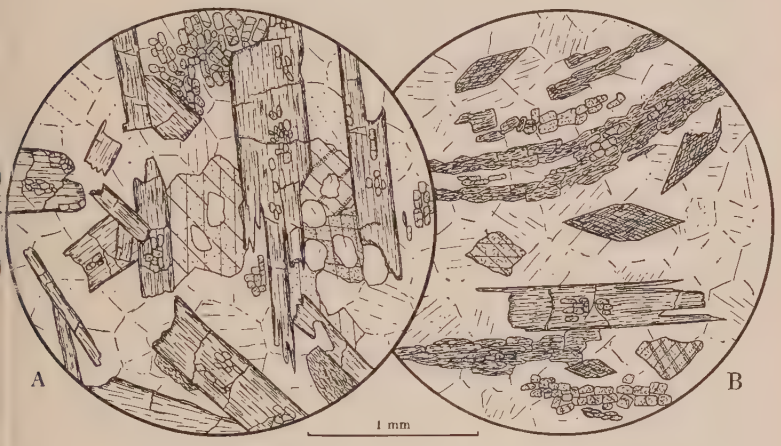

Fig. 2 A. As in fig. 1 A and B.

Fig. 2 B. Section of albite-epidote-actinolite-chlorite-calcite-schist (no. 2718) cut perpendicular to the schistosity, showing end-sections of porphyroblastic actinolite. From Coronet Peak, western Otago, New Zealand.

		Metal atoms.		Metal groups.	Ideal tremolite formula.
SiO_2	52·19	7·474		8·00	8
Al_2O_3	3·93	0·653	0·526 + 0·127		
TiO_2	0·40	0·043		5·09	5
Fe_2O_3	4·85	0·516			
FeO	10·73	1·281			
MnO	trace	—			
MgO	14·54	3·123			
CaO	10·20	1·566		1·98	2
SrO	nil	—			
Na_2O	1·53	0·412			
K_2O	0·03	—			
H_2O+	2·17	2·064		2·06	2
H_2O-	0·02	—			
	100·59				

Formula: $(OH)_2(Na,Ca)_2(Mg,Fe,Ti,Al)_5(Si,Al)_8O_{22}$.

Amphibole from albite-epidote-actinolite-chlorite-calcite-schist (no. 2718), Coronet Peak, western Otago, New Zealand. Analyst, C. O. Hutton.

[1] B. E. Warren, The crystal structure and chemical composition of the monoclinic amphiboles. Zeits. Krist., 1930, vol. 72, pp. 493–517. [M.A. 4–278.]

An interesting but rare feature in this amphibole is the zonary arrangement whereby a nucleus with totally different optical properties passes without perceptible break into the amphibole just described. This nuclear crossite type of amphibole is elongated in the direction of the vibration-direction β and has a transverse optic axial plane. The maximum extinction-angle obtained for $\beta:c = 8°\pm2°$. Owing to the small size of the nucleus and the zonary arrangement, 2V could not be

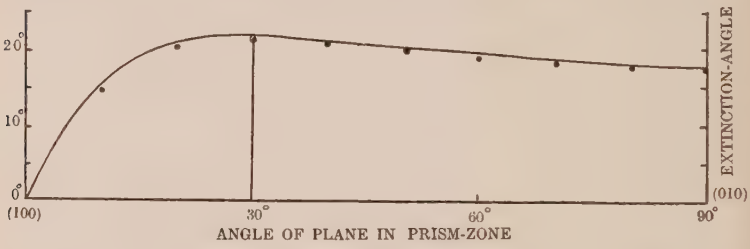

Fig. 3. Curve showing values of the extinction-angles in any plane in the prism zone of a monoclinic crystal when $2V = 60°$, $\gamma:c = 18°$, and $\beta = b$. The continuous line represents values obtained on the universal stage, while the dots are the values obtained stereographically.

measured with any great accuracy, but appears to be approximately $30°\pm5°$. It should be pointed out that the extinction-angle of 8° is rather greater than that usually given, but Larsen[1] has described two crossites with $\beta : c$ about 7° and 10°. Pleochroism is striking and follows the scheme α pale mauve to colourless, β deep blue, and γ deep mauve; absorption $\beta > \gamma > \alpha$. Dispersion of the bisectrices is strong and the birefringence is low.

This condition of a transverse optic axial plane is realized only in amphiboles such as crossite, laneite, osannite, taramite, fluotaramite (J. Morozewicz[2]), and crocidolite. Murgoci[3] believes that transverse axial planes may be developed in most amphiboles, even in actinolites, but the writer is not clear what Murgoci means in this latter case, for any member of the series from tremolite to ferrotremolite always has the optic axial plane parallel to (010). It should be noted that Murgoci[4]

[1] E. S. Larsen, The microscopic determination of the nonopaque minerals. Bull. U.S. Geol. Surv., 1921, no. 679, p. 64.

[2] J. Morozewicz, Min. Abstr., 1926, vol. 3, pp. 109–110.

[3] G. Murgoci, Contributions to the classification of the amphiboles. Bull. Dept. Geol. Univ. Calif., 1906, vol. 4, no. 15, pp. 359–386.

[4] G. Murgoci, Sur les propriétés des amphiboles bleues. Compt. Rend. Acad. Sci. Paris, 1922, vol. 175, pp. 372–374. [M.A. 2–221.]

classes osannite with those amphiboles having a transverse optic plane, but later in the same year he[1] groups it with riebeckite which has an optic plane parallel to (010).

The optical properties of this rare amphibole situated in the centre of the blue actinolite porphyroblasts are most comparable with those of crossite, an intermediate member of Kunitz's glaucophane-riebeckite series[2] (p. 198). Woyno[3] in a petrological treatment of the Casanna schists finds sodic amphiboles such as glaucophane (pp. 157–159) and crossite (pp. 159–160) important constituents. For crossite he gives the following pleochroism and optical properties: α wine-gold, β blue, γ violet-grey; optic axial plane normal to the symmetry-plane and the angle between β of the refractive index ellipsoid and c is 16° 5′. From New Zealand, Turner[4] (p. 341) describes a closely similar amphibole from a low-grade chlorite-epidote-albite-schist, in which $\beta : c = 28°$. After a consideration of all the properties he comes to the conclusion that the mineral agrees best with crossite.

The writer wishes to thank Professor C. E. Tilley for his criticism and help in connexion with this paper.

[1] G. Murgoci, Sur la classification des amphiboles bleues et de certains hornblendes. Ibid., pp. 426–429. [M.A. 2–221.]

[2] W. Kunitz, Die Isomorphieverhältnisse in der Hornblendegruppe. Neues Jahrb. Min., Abt. A, 1930, Beil.-Bd. 40, pp. 171–250. [M.A. 4–200.]

[3] T. J. Woyno, Petrographische Untersuchung der Casannaschiefer des mittleren Tagnetales (Wallis). Neues Jahrb. Min., 1912, Beil.-Bd. 33, pp. 136–207.

[4] F. J. Turner, Metamorphism of the Te Anau Series in the region north-west of Lake Wakatipu. Trans. Roy. Soc. N.Z., 1935, vol. 65, pp. 329–349.

An X-ray examination of mordenite (ptilolite).

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[Read June 9, 1938; communicated by B. Mouat Jones.]

I. *Introduction.*

THE structures of the fibrous zeolites edingtonite, thomsonite, and natrolite (with scolecite and mesolite) were determined by X-ray methods some years ago [1], and it was suggested shortly afterwards by M. H. Hey and F. A. Bannister in a private communication to one of us (W.H.T.) that 'ptilolite', another zeolite of fibrous habit, might prove to have a similar structure. An X-ray rotation photograph about the needle axis indicated a unit-cell dimension along the needle axis of approximately 7·5 Å., quite different from the axis c 6·6 Å. characteristic of the fibrous zeolites previously examined, and no further examination of 'ptilolite' was made at that time. We have now determined the unit cell and space-group of this crystal, and further work is in progress with a view to the complete analysis of the structure. This paper presents an account of the experimental data which we have obtained.

In the meantime a certain confusion in the naming of the mineral has been removed by the work of Hey and Bannister in the course of their systematic investigation of zeolites. In works of reference (for example, Dana's 'System of Mineralogy', Hintze's 'Handbuch der Mineralogie') the name mordenite is applied to a platy zeolite similar in habit and composition to heulandite, while ptilolite is applied to a zeolite of fibrous habit; and the platy 'mordenite' has also been named clinoptilolite by Schaller [2]. Hey and Bannister [3] have shown, however, that the platy mordenite (clinoptilolite) is structurally identical with heulandite, and is merely a silica-rich variety of that mineral; while the original fibrous mordenite of How is structurally identical with (fibrous) ptilolite, and is quite different from heulandite. They therefore, on grounds of priority, apply the name mordenite to the fibrous zeolite commonly known as ptilolite. This nomenclature is adopted in the present paper.

II. *Experimental Data.*

We have examined ptilolite from San Piero in Campo, Elba, Italy (B.M. 1914,321), mordenite from Aros, Isle of Mull, Scotland (B.M. 47614), and flokite from Iceland (B.M. 1932,1297). The appearance, under the microscope, of crystals from Elba and from Mull indicates that twinning

r parallel growth is common, and this is confirmed by the nature of ne X-ray diffraction-spots obtained on rotation photographs. The -ray data quoted below have been obtained from small crystal fragents selected because of their apparent freedom from twinning and arallel growth.

(i) *Specific Gravity.*—The specific gravities of small fragments of ordenite from Elba and Mull have been determined by flotation in mixture of chloroform and bromoform: they are 2·15 ± 0·01 (Elba) nd 2·12 ± 0·01 (Mull). According to Callisen [4] the specific gravity of okite is 2·102.

(ii) *Pyroelectricity.*—The results of pyroelectric tests by the method f cooling in liquid air are inconclusive. Some specimens show a fairly efinite, though weak, effect; other specimens from the same locality how no trace of the effect. In every case where the effect is observed, ne electric charges are located at the ends of the needle axis, which is herefore the polar axis. Different specimens may perhaps be expected yield inconclusive results from pyroelectric tests since parallel growths nd twin growths are common.

(iii) *Symmetry.*—The crystals selected as being free from parallel rowth and twinning are lath-shaped fragments with dimensions of the rder 1 × 0·2 × 0·05 mm. The extinction on the plate face of the crystal parallel or nearly parallel to the needle axis, and the extinction on section perpendicular to the needle axis is parallel to the plate face. he symmetry may therefore be assumed to be approximately orthohombic with the *c*-axis [001] parallel to the needle axis, and with the late face as pinakoid (100).

A Laue photograph taken with the X-ray beam normal to the plate ace and so parallel to the assumed orthorhombic *a*-axis [100] shows eflection planes parallel and perpendicular to the needle axis, i.e. arallel to planes (010) and (001) in the assumed orthorhombic cell. urther confirmation of the orthorhombic symmetry is obtained in umerous oscillation photographs.

In some crystal fragments the extinction on the plate face (orthohombic (100)) is not quite parallel to the needle axis: this departure om straight extinction would suggest that the true symmetry is monolinic and only pseudo-orthorhombic. In a private communication Ir. F. A. Bannister informs us that his X-ray data conform to the requirements of orthorhombic symmetry, but that the extinction on the late face may be inclined to the needle axis by as much as 4°, the xtinction-angle apparently varying with the chemical composition.

It is therefore probable that the true symmetry is monoclinic, but that the structure is very closely pseudo-orthorhombic; the departure from the higher symmetry is too small to be revealed by X-ray methods, but is shown by the highly sensitive optical properties. Such pseudo-symmetry is frequently observed in complex structures of this type [5].

(iv) *Unit cell and space-group.*—The axial lengths of the orthorhombic unit cell, deduced from measurements on oscillation photographs obtained from a crystal from Mull, are a 18·25±0·1, b 20·35±0·1, c 7·50±0·05 Å., the c-axis being the needle axis, the (100) plane the plate face of the crystal.

All reflections (hkl) are absent if ($h+k$) is odd, and the cell is therefore centred on the c face (001). Also, reflections ($h0l$) are absent if either h or l is odd, reflections ($0kl$) are absent if k is odd, present when l is either odd or even, and reflections ($hk0$) are present when h and k are either both odd or both even, absent if ($h+k$) is odd. Possible space-groups [6] are therefore $D_{2h}^{17} = Cmcm$, $C_{2v}^{12} = Cmc$, and, with interchange of a- and c-axes, $C_{2v}^{16} = Ama$. If the last space-group is selected, the polar axis is normal to the plate face of the crystal; the pyroelectric tests indicate, however, that if the crystal is truly polar the needle axis must be the polar axis, and it is therefore probable that the space-group is $C_{2v}^{12} = Cmc$, assuming, of course, that the symmetry is orthorhombic.

(v) *Contents of the unit cell.*—The formula of ptilolite is given by Hintze (1897, vol. 2, p. 1824) as $(Ca,K_2,Na_2)Al_2Si_{10}O_{24}+5$(or 7)$H_2O$, while Callisen [4] gives as the formula of flokite $H_8(Ca,Na_2)Al_2Si_9O_{26}.2H_2O$ which is equivalent to $(Ca,Na_2)Al_2Si_9O_{22}.6H_2O$ when all the hydrogen is assumed to be present as water.

We have calculated the cell contents for flokite, on the basis of Callisen's published density and analysis [4], and assuming an orthorhombic unit cell with edges a 18·25, b 20·35, c 7·50 Å. The composition of flokite is SiO_2 67·69, Al_2O_3 12·43, CaO 2·65, MgO 0·09, Na_2O 4·36, H_2O+ 8·82, H_2O- 4·53, total 100·57; the density is 2·102, and the unit cell therefore contains $Ca_{1\cdot7}Na_{5\cdot0}Al_{8\cdot7}Si_{40\cdot0}O_{97\cdot2}+26H_2O$.

Similarly, we have calculated the cell contents for the Elba mordenite (ptilolite) (B.M. 1914,321) assuming the same orthorhombic unit cell; the specific gravity is 2·15, and the composition as determined by D'Achiardi [7] is SiO_2 65·21, Al_2O_3 11·20, CaO 3·77, MgO trace, alkalis 6·07, H_2O+ 10·11, H_2O- 4·11, total 100·47. The alkalis are not separated and are stated to consist mainly of sodium, with spectroscopic indications of potassium, lithium, and caesium. Assuming the alkali to be pure Na_2O the unit cell contains $Ca_{2\cdot4}Na_{7\cdot1}Al_{8\cdot0}Si_{39\cdot5}O_{96\cdot9}+28\cdot4H_2O$.

ssuming the alkali to be pure K_2O the unit cell contains $Ca_{2\cdot4}K_{4\cdot7}$ $_{8\cdot0}Si_{39\cdot5}O_{95\cdot7}+28\cdot4H_2O$. No analysis of the Mull mordenite is available. Great accuracy is not claimed for the measurements of either specific avity or unit cell dimensions, but the above calculations may be ken to indicate that the unit cell of mordenite contains a group ideally presented by $Ca_4Al_8Si_{40}O_{96}+28H_2O$, i.e. four molecules of composition $Al_2Si_{10}O_{24}.7H_2O$. In the mineral, calcium is partly replaced by sodium id potassium, and the water content is variable, probably depending on the vapour pressure of the surrounding atmosphere, as is suggested Hintze (loc. cit.) in the case of ptilolite analyses made at Denver and Washington.

III. *Nature of the Structure.*

In attempting to deduce the structure of mordenite two initial diffi- lties are encountered. In the first place, the optical properties indicate onoclinic symmetry, while the X-ray data conform to the requirements orthorhombic symmetry. This difficulty is probably more apparent an real: it seems reasonable to suppose that the structure approxi- ates very closely indeed to one of orthorhombic symmetry—so closely, fact, that no difference can be detected by X-ray methods. Secondly, suming orthorhombic symmetry, the choice of space-group depends on the results of the pyroelectric tests; if the crystal is pyroelectric e space group is $C_{2v}^{12} = Cmc$, otherwise it is $D_{2h}^{17} = Cmcm$. By analogy th the case of thomsonite [1], it is legitimate to suggest that to a first proximation the structure may perhaps possess holohedral symmetry, e actual polar structure being only a slight distortion of the holohedral ucture. Only after completion of the structure analysis will it be ssible to decide this point.

It is highly probable that this zeolite structure is based on a frame- ork of linked SiO_4 and AlO_4 tetrahedra, with water molecules and tions located in cavities existing within the relatively rigid framework. he unit cell contains 48 tetrahedra, and the symmetry of the crystal low (even if holohedry is assumed), so that it is difficult to test the rrectness of any assumed tetrahedron framework by comparing served and calculated intensities of reflection. We have discovered e arrangement of 48 tetrahedra per unit cell, of the right dimensions, d possessing the holohedral symmetry of $D_{2h}^{17} = Cmcm$, but we have far been unable to prove that this structure, or any slight modification it, is capable of explaining the observed intensities of reflection. rther work is in progress.

IV. *Summary.*

Specimens of the fibrous zeolite mordenite (ptilolite) have been examined by X-ray methods, and the specific gravity and pyroelectric properties determined. Laue and oscillation photographs indicate that the structure possesses orthorhombic symmetry, and the unit cell, with edges a 18·25, b 20·35, c 7·50 Å., contains four molecules of composition $(Ca,Na_2,K_2)Al_2Si_{10}O_{24}.7H_2O$. The space-group is either $D_{2h}^{17} = Cmcm$ or $C_{2v}^{12} = Cmc$; the pyroelectric tests are somewhat inconclusive, but indicate that the c-axis [001] is probably polar. The structure is probably based on a framework of linked tetrahedra.

We are indebted to Messrs. M. H. Hey and F. A. Bannister for helpful discussion and for the supply of material through the Trustees of the British Museum, and to Mr. S. H. Chao for assistance in obtaining some of the X-ray photographs.

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The leaching of granite and some other rocks.

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[Read June 9, 1938.]

[N 1913 the late Mr. J. J. Beringer suggested that it would be of interest to determine the solubility of crushed felspar (*a*) in distilled ater free of carbon dioxide, and (*b*) in distilled water saturated with rbon dioxide. For this purpose crushed felspar (orthoclase) was vered with water in a silica basin (i) in a desiccator containing potas- um hydroxide solution, and (ii) in a desiccator connected with a carbon oxide Kipp's apparatus. These were allowed to stand for a fortnight d the alkalinity of the water was then determined by $N/100$ hydro- loric acid. This experiment was continued until the end of July, 1914. definite solubility was determined in each case and the solubility in e carbon dioxide water was only slightly more than in the water free m carbon dioxide. Unfortunately Mr. Beringer died early in 1915, d the records of his experiment could not be found.

In 1934 I began the experiments to be described below. It seemed visable to reproduce the conditions under which superficial granite percolated by rain-water but, at the same time, to stimulate the action using crushed granite so as to expose a greater surface to the perco- ing water. The experiment was therefore set up as follows.

A sample of fresh, unaltered muscovite-biotite-granite from Long wns, near Penryn, Cornwall, was crushed to pass a 30-mesh sieve and on a 50-mesh sieve; 450 grams of the crushed rock was placed in a ss separating funnel (fig. 1) with a plug of glass-wool at the bottom prevent choking of the glass tap. A flask fitted with a rubber cork d two tubes, one of which extended from about half-way up the ck of the flask to 4 inches below the cork, its upper end being drawn t to a fine jet; the second tube extended from the bottom of the neck the flask to outside the cork where it was bent at 30° and its outer end ed with a rubber tube and screw pinch-cock, while its upper end s drawn out to a fine jet. This flask was filled with 800 c.c. of distilled ter and inverted over the separating funnel, the pinch-cock being so justed that air bubbled slowly into the flask, while water dripped into

the funnel. In this way the water was thoroughly aerated. The outflow from the separating funnel was delivered into a glass funnel, fitted with filter-paper, which was placed in the neck of an empty flask.

Fig. 1. Leaching apparatus.

After the first 800 c.c. of water had passed through it was returned to the upper flask and allowed to drip through again. This was repeated until the water had dripped through the funnel five times. The water was then transferred to a porcelain dish, evaporated to a small volume, transferred to a weighed silica crucible, evaporated to dryness, and weighed. A fresh 800 c.c. of distilled water was then placed in the upper flask and the leaching repeated.

This experiment was repeated until fifteen lots of water had been evaporated, when an accident brought the experiment to a close. The results are given in table I (column 1). A new experiment was started in 1936 and was carried on until 25 lots of water had been evaporated, and the results are given in column 2.

The time taken for the water to pass through five times varied somewhat, especially as the experiment was stopped on Sundays, but neglecting this interruption, the average time was 5 to 6 days. It was observed that, after the water had passed through the funnel twice, rusty-red haloes appeared round the flakes of biotite. The sediment collected in the filter-paper was very little, its total weight after 25 leachings being only 0·008 gram. The dried soluble portion was rusty-brown in colour.

To determine the solubility of the apparatus, three blank experiments were carried out with a separating funnel filled with glass-wool. The solubles recovered after evaporation were, 0·00056, 0·00071, and 0·00062 gram.

In 1936 a similar experiment was begun using oolitic limestone of the Oolite formation from Corsham quarry, near Bath, crushed to pass a 30-mesh sieve and lie on a 50-mesh sieve. The experiment was carried out in exactly the same way as in the case of the granite and was continued until 25 lots of water had been evaporated (table I, column 3). The dried material was dark cream-coloured. It was observed that after five leachings, calcium carbonate was deposited

etween the grains of the oolite; also, the effluent water was sometimes loudy with calcium carbonate. The sediment caught in the filter-paper as larger than in the case of the granite and gave a total weight of ·12 gram.

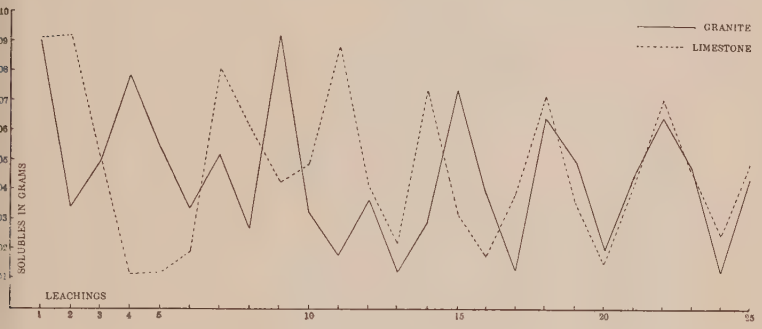

FIG. 2. Leaching of granite (2) and limestone, plotted from Table I.

TABLE I. Leaching of granite, limestone, and gabbro.
Weight in grams of solubles, each number being for five leachings.
(Temperatures: maximum 71°, minimum 57°, average 68° F.)

	Granite (1).	Granite (2).	Limestone.	Gabbro.
1.	0·071	0·090	0·091	0·048
2.	0·050	0·034	0·092	0·0201
3.	0·017	0·0498	0·051	0·027
4.	0·042	0·079	0·0113	0·0582
5.	0·0825	0·054	0·0118	0·0242
6.	0·0481	0·0335	0·019	0·036
7.	0·018	0·0518	0·081	0·0302
8.	0·021	0·027	0·061	0·048
9.	0·052	0·092	0·0428	0·031
10.	0·079	0·033	0·049	0·3227
11.	0·0611	0·0181	0·089	
12.	0·0287	0·037	0·0415	
13.	0·045	0·012	0·0219	
14.	0·0829	0·0288	0·074	
15.	0·057	0·074	0·032	
Total	0·7553			
16.		0·0388	0·0157	
17.		0·013	0·039	
18.		0·075	0·072	
19.		0·050	0·037	
20.		0·020	0·0153	
21.		0·046	0·042	
22.		0.075	0·071	
23.		0·048	0·047	
24.		0·0118	0·025	
25.		0·0451	0·050	
Total		1·1367	1·1823	

Quite recently a third experiment has been started in which the rock leached was gabbro. The results of this experiment, to date, are given in column 4.

The total solubles obtained in the second leaching of granite and in the leaching of oolitic limestone were analysed by Dr. F. W. Rixon of Bristol University, and the results are given in table II.

TABLE II. Chemical analyses of solubles.
(Materials dried at 110° C.)

	Granite (2).	Limestone.
SiO_2	6·36%	5·25%
Al_2O_3	1·01	—
Fe_2O_3	3·50	0·95
MgO	10·85	trace
CaO	45·10	44·35
Na_2O	3·64	8·84
K_2O	3·18	trace
CO_2	n.d.*	n.d.†
Cl	—	9·34
I	—	trace
SO_3	—	15·20
H_2O	n.d.	n.d.
Organic matter	—	1·90
	73·64	85·83

* Slight effervescence with HCl.
† Strong effervescence with HCl.

The graphs (fig. 2) emphasize the fact that the amounts dissolved in leaching both the granite and oolite show a fairly regular rise and fall. This variation is not due to change of temperature, as it persists when the temperature is constant. It seems to the author that some type of delayed action takes place, due possibly to the formation of intermediate hydrated compounds.

The leaching experiments will be continued, and it is intended to use water which has stood over peat.

The identity of zinckenite and keeleyite.

(With Plate X.)

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[Read June 9, 1938.]

ZINCKENITE was first described in 1826 by G. Rose, who determined it to be an orthorhombic mineral. The crystals were thought to be seldom single, but to occur in nearly hexagonal forms as a result of twinning in some fashion similar to that found in aragonite. The presence of longitudinal striations on the lateral faces was taken as further evidence that the crystals were twinned. The composition was given by H. Rose as $PbSb_2S_4$ or $PbS.Sb_2S_3$. The original specimens which were described came from the antimony mine of Wolfsberg in the Harz.

In 1922 S. G. Gordon described a new lead sulfantimonite from Oruro, Bolivia, which he named keeleyite. This mineral he presumed to be orthorhombic, although no measurable crystals were found, and the formula was given as $Pb_2Sb_6S_{11}$ or $2PbS.3Sb_2S_3$. On the basis of this analysis the mineral was assigned to the 'acidic division'. Some question was raised at the time by reviewers as to the validity of the mineral as a distinct species, and the reliability of the formula involved was also doubted.

The first analysis, made by Whitfield, had been corrected on the basis that the contaminating sulphide was chiefly chalcopyrite, although it was later found that in reality this was stannite. Accordingly, Shannon and Short in 1927 conducted a new investigation in an endeavour to ascertain the true status of keeleyite in the light of the above change of contaminant. They conducted various mineragraphic and microscopic examinations which led them to the conclusion that this mineral was in reality sufficiently different in reaction from zinckenite to be considered a separate species. They made a new analysis, in order to correct the assumption with respect to the contaminating sulphide, and deduced the formula $PbS.Sb_2S_3$. This is, of course, the same formula as that given by Dana for zinckenite, but Shannon and Short

say that the only other explanation of the difference between keeleyite and zinckenite is that the formula commonly ascribed to zinckenite is wrong and that this mineral actually has the formula $2PbS.3Sb_2S_3$ or $3PbS.4Sb_2S_3$.

E. T. Wherry, who had earlier objected to the acceptance of keeleyite as a distinct species on the grounds that it was merely a variety of zinckenite, disagreed with the conclusions of Shannon and Short. He pointed out that the mineral was originally described 'on the basis of an erroneous recalculation of a commercial analysis on an impure specimen', with the result that the formula, to say the least, was unconvincing. He was not in agreement with Shannon and Short's thesis that the mineral was entitled to species rank merely on the basis that they had found present in keeleyite 3·26 % of metals other than lead, as well as certain mineragraphic differences, when compared with another sulphosalt about which no data was given except to say that the specimen was labelled zinckenite. He felt that the sole claim for keeleyite, therefore, rested on the presence of a little more than 1 % of zinc and a few mineragraphic differences as compared to a specimen which may, or may not, have represented zinckenite, or conformed to the ratio $PbS.Sb_2S_3$. He maintained, on the contrary, that they had succeeded only in demonstrating that keeleyite has the zinckenite formula, although there is sufficient replacement of the lead to account for the small differences observed in properties, and hence is merely an impure variety of zinckenite.

The object of the present work was to attempt to shed further light on this question through examination of the minerals by means of single-crystal X-ray diffraction photographs. It was fortunate that, among other material available for examination in the British Museum collections, there were found two specimens, one of each variety, which might be said to be the original material in each case. The first specimen (B.M. 88830), zinckenite, Wolfsberg, Harz, was purchased from H. Heuland, 17 November 1829, and a note on the accompanying label conveys the information that it was presented to Heuland by G. Rose, and therefore undoubtedly represents material identical with that which Rose employed. The second specimen (B.M. 1924,145), labelled keeleyite (type) and stannite, San José Mine, Oruro, Bolivia, is a portion of the original specimen.

Single-crystal photographs were taken of several crystals from each of these specimens, both by rotation and oscillation methods (pl. X, figs. 1–3). It was found that rotation photographs of a crystal from the

keeleyite specimen were in perfect agreement with corresponding rotation photographs of a crystal from the Heuland specimen. From this we conclude that the unit cells of the two specimens are the same, and therefore that keeleyite is identical with zinckenite. A specimen labelled keeleyite from Baia Mare (= Nagybánya), Romania (B.M. 937,44), was also examined and proved to be the same material.

Zinckenite was originally described by Rose as being orthorhombic, and other writers have attributed the hexagonal form of the crystals is due to twinning. However, Laue photographs reveal that it is really a hexagonal mineral. No evidence was found in any of the photographs to support any theory of twinning which might produce pseudo-hexagonal crystals. The cell sides were measured on crystals from specimen B.M. 1906,213, Wolfsberg, Harz, by means of a series of oscillation photographs. These were found to be a 4·06, c 8·60 A. Both the Laue and the oscillation photographs show that there are no vertical planes of symmetry, and only the even orders of the (0001) diffractions occur. Hence the space-group is either $C_6^6 = C6_3$ or $C_{6h}^2 - C6_3/m$. The odd layer-lines on oscillation photographs about the a- and c-axes are very weak so that there is a well-marked pseudo-cell of dimensions a 22·03, 4·30 Å. with the same space-group. Moreover most of the spots on the weak layer-lines show a spread which suggests in a lesser degree the disorder effect recently reported by L. W. Strock (1936) for silver iodide. W. Hofmann (1935) has measured the spacing in the direction of elongation of a few sulpharsenites, sulphantimonites, and sulphobismuthites of copper, silver, and lead. He reports a pseudo-period of 4·33 Å. for zinckenite, in close agreement with our value of $2 \times 4{\cdot}30$ Å. Our measurements, however, do not agree with those of Ferrari and Curti (1934), who gave a 6·37, b 3·81, c 14·53 Å. Their values a/b and c/b are related to Dana's axial ratios by the multiples 3:1:6. There is no obvious explanation of the discrepancy. Short exposure photographs might lead to an erroneous choice of axes.

Formerly the isomorphism of zinckenite with sartorite, chalcostibite, and emplectite has been considered to rest upon their similarity of chemical formulae and crystallography. Palache and Peacock (1933) in a recent study of emplectite show that zinckenite can be set up so that its few crystal forms can be related to those of the isomorphous, orthorhombic pair, emplectite and chalcostibite. This agreement, however, they regard only as provisional and say that zinckenite is the most imperfectly known member of the group. It should be added that still less is known about galenobismutite.

Dana (1892), from Rose's early measurements on zinckenite, indexed the two prism and dome forms as (102) and (061), deducing the axial ratios $a:b:c = 0{\cdot}5575:1:0{\cdot}6353$. This setting, in which the elongation of the mineral is chosen for the *b*-axis, was adopted by Dana because he was convinced that sartorite and zinckenite are isomorphous. Luedecke (1896), however, reverted to Rose's orientation in which the elongation is parallel to the *c*-axis, and Dana's forms (102) and (061) become (110) and (104) with the axial ratios $a:b:c = 0{\cdot}5698:1:0{\cdot}5978$.

Groth and Mieleitner (1921) adopted Luedecke's orientation, changing the indices of Luedecke's (104) to (101), giving axial ratios $a:b:c = 0{\cdot}5693:1:0{\cdot}1495$. They therefore separated zinckenite from emplectite and chalcostibite, but did not exclude the possibility that the mineral might be monoclinic and isomorphous with sartorite, for which latter they adopted Trechmann's symmetry and setting. V. Goldschmidt (1923) interchanged the *a*- and *b*-axes of Dana's setting and the form (061) becomes (301), yielding axial ratios $a:b:c = 0{\cdot}8976:1:1{\cdot}140$. L. J. Spencer (1897) published further measurements on zinckenite from Wolfsberg in the Harz and used Dana's setting, adding *c* (001) to the forms already observed by Rose and Luedecke. X-ray photographs show that the crystals he studied are zinckenite, but his forms (001) and (102) should be interchanged.

The axial ratio of zinckenite using the X-ray measurements is $c = 8{\cdot}60/44{\cdot}06 = 0{\cdot}195$. Dana's (102) and (061) and Spencer's (102) then become $m\,(10\bar{1}0)$, $(22\bar{4}3)$, and $a\,(11\bar{2}0)$ respectively. The interfacial angles $(22\bar{4}3):(\bar{2}\bar{2}43)$ and $(10\bar{1}0):(22\bar{4}3)$ calculated from the X-ray measurements are 29° 10′ and 77° 24′ respectively, compared with Rose's measured values 29° 24′ and 77° 11′ to 77° 26′. Rose's measured values for the prism angle varied from $55\frac{1}{2}°$ to $61\frac{1}{2}°$. They should, of course, all be equal to 60°. L. J. Spencer has commented on the difficulty of measuring the prism zone of zinckenite, which he found gave a continuous band of images. He did, however, obtain values for $m\,(10\bar{1}0) \wedge a\,(11\bar{2}0)$ of 29°–31°. Our measurements of the small prism of zinckenite from Wolfsberg used for the X-ray photographs showed, amidst a mass of reflections from vicinal faces in the prism zone, two good images yielding an interfacial angle of 30° 8′. One of these, $a\,(11\bar{2}0)$, is parallel to a poor cleavage on the crystal. The vicinal faces include two further faces of the form $(10\bar{1}0)$ which yield values 59° 14′ and 64° 4′ respectively. One other face of the form $a\,(11\bar{2}0)$ is present inclined at 60° 52′. A face corresponding to $(31\bar{4}0)$ was also observed, but in accordance with the lack of symmetry already revealed by X-ray

hotographs (13$\bar{4}$0) is absent. The final proof of the true symmetry of inckenite rests on the X-ray measurements. The habit of growth of ie mineral, rather like the radiating fibrous nodules of pyrite from the halk of the south of England, is not conducive to well-developed prism rms and many of the specimens in the British Museum carry evidence f furrowing and etching from solution after crystallization.

The following table shows the relation between the various settings hich have been adopted for zinckenite and the new X-ray setting. he axial ratios calculated from X-ray data are given in square brackets.

Dana (1892)	$a:b:c = 0{\cdot}5575:1:0{\cdot}6353$ [0·555 : 1 : 0·641]
Luedecke (1896)	$a:b:c = 0{\cdot}5698:1:0{\cdot}5978$ [0·577 : 1 : 0·601]
Groth and Mieleitner (1921)	$a:b:c = 0{\cdot}5693:1:0{\cdot}1495$ [0·577 : 1 : 0·150]
Goldschmidt (1923)	$a:b:c = 0{\cdot}8967:1:1{\cdot}140$ [0·901 : 1 : 1·154]
Vaux and Bannister	$a:c = 1:0{\cdot}195$

A critical examination of the chemical analyses of zinckenite, inuding keeleyite, reveals that only five out of eleven can be regarded suitable for the determination of the chemical composition. The maining six have been rejected on the score of very bad summations id excess of positive or negative valencies. The sulphur content of the it cell of zinckenite has been calculated direct from the five fairly od chemical analyses and the X-ray and specific gravity measureents.

Table I. Atomic contents of the unit cell of zinckenite.

	1.	2.	3.	4.	5.	5a.
Pb	70·7	67·0	76·0	64·9	63·6	64·4
Cu	3·0	—	5·1	4·5	—	—
Ag	—	—	—	2·2	—	—
Fe	—	—	0·5	6·8	0·6	0·6
Sb	167·7	171·0	158·9	162·2	170·5	172·7
S′	324·4	328·4	323·1	328·8	333·8	323·7
Σm... ...	73·7	67·0	81·6	87·6	64·2	65·0

S′ Sulphur atoms calculated from chemical analysis, specific gravity, and X-ray ta.

Σm = Pb+Cu+Ag+Fe; in no. 4 also some Zn and Sn.

1. Wolfsberg, Harz. H. Rose, 1826.
2. Ludwig mine, Adlersbach, Kinzigthal, Baden. H. A. Hilger, 1877.
3. Wolfsberg, Harz. C. Guillemain, 1898.
4. Oruro, Bolivia. E. V. Shannon and M. N. Short, 1927.
5. Baia Mare, Romania. I. de Finály and S. Koch, 1929.
5a. No. 5 recalculated subtracting sulphur.

Table I shows that the sulphur content varies from 323·1 to 328·4. om space-group considerations we have assumed the probable mber to be 324, i.e. an exact multiple of 6. On this basis the number

of antimony, lead, &c. atoms has been calculated, and table I shows that the antimony content is 158·9 to 172·7 atoms per unit cell and for lead, copper, &c. 65 to 87·6 atoms per unit cell. Bearing in mind the hexagonal symmetry of the mineral, we regard these indifferent analyses as showing that the antimony and the lead, copper, &c. contents approximate to 168 and 72 respectively. Only H. Rose's original analysis gives full support to this conclusion, and of the remainder nos. 2 and 5a give figures nearer to the ideal than do nos. 3 and 4. On the whole, the evidence suggests a closer approach to $Pb_{72}Sb_{168}S_{324} = 12(6PbS.7Sb_2S_3)$ than to $Pb_{81}Sb_{162}S_{324} = 81(PbS.Sb_2S_3)$. Zinckenite, therefore, both in its chemical composition and symmetry, is not to be regarded as isomorphous with sartorite, emplectite, and chalcostibite. The unit-cell dimension parallel to the elongation of these minerals and many others, including stibnite, jamesonite, plumosite, baumhauerite, rathite, and dufreynosite, are of the same order or a simple multiple thereof (see table II). Thus there is probably some structural relationship running throughout the large family of sulphantimonites and sulpharsenites, which, however, even for apparently simple chemical compounds like sartorite and emplectite, does not extend to isomorphism.

Table II. Symmetry and formulae of zinckenite and related minerals.

	System.	*a*.	*b*.	*c*.	Contents of unit cell.
Zinckenite	... Hexagonal	44·06	(76·31)	8·60Å	$12Pb_6Sb_{14}S_{27}$
Sartorite	... Monoclinic ($\beta = 90°$)	58·38	7·79	83·30	$240PbAs_2S_4$
Chalcostibite	... Orthorhombic	6·008	3·784	14·456	$4CuSb_2S_4$
Emplectite	... Orthorhombic	6·125	3·890	14·512	$4CuBi_2S_4$

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Explanation of Plate X.

X-ray photographs of a single crystal of zinckenite (B.M. 1906,213) from Wolfsberg, Harz.

All the photographs were taken with filtered Cu-K_α radiation, $\lambda = 1{\cdot}539$ Å., a cylindrical camera of diameter 6·04 cm. A length of 20 cm. on the original film is equivalent to 15 cm. on the reproduced figures.

Fig. 1. Rotation photograph about the axis $[11\bar{2}0]$.

Fig. 2. Rotation photograph of the same crystal about the axis [0001].

Fig. 3. Oscillation photograph through 5° of the same crystal about the axis $[10\bar{1}0]$. Owing to the large unit-cell dimensions perpendicular to the *c*-axis, series of spots corresponding to planes with the same *l* value lie on well-marked curves.

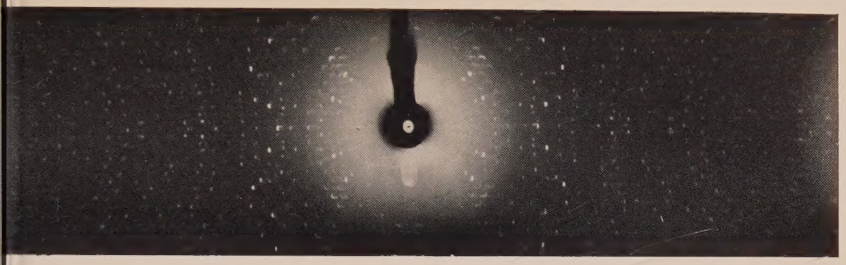

Fig. 1

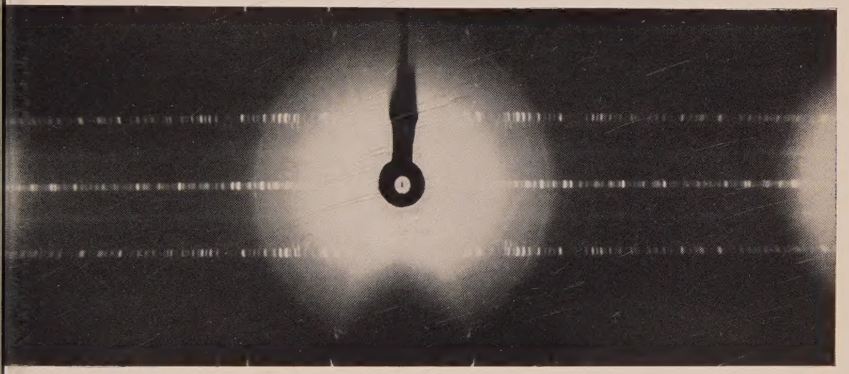

Fig. 2

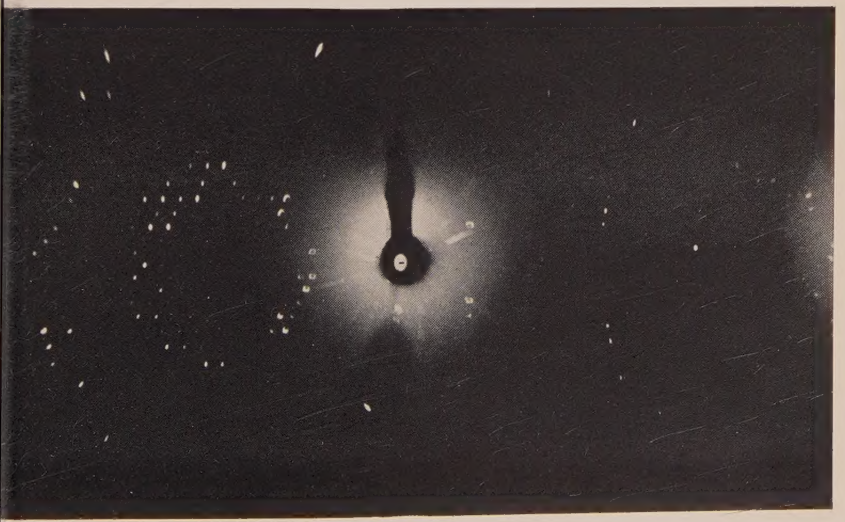

Fig. 3

G. Vaux and F. A. Bannister: X-ray Photographs of Zinckenite